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ORE DEPOSITION AND ENRICHMENT AT ENGELS, CALIFORNIA.[1]

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[1] This is one of a series of contributions by the Secondary Enrichment Investigation that are intended to present the results of specific portions of its work in advance of the complete memoir.

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INTRODUCTION AND CONCLUSIONS.

The Engels copper mine, located in northern Plumas County, California, 27 miles northeast of Keddie on the Western Pacific Railroad, lies at an elevation of about 5,200 feet on a gentle, forested slope that descends toward the southwest from the crest of one of the eastern ridges of the Sierra Nevada. The property has been worked more or less steadily for many years, but has suffered because of remoteness from rail transportation and of difficulty in either smelting or concentrating the bornite-chalcopyrite ore which it chiefly yields. The installation of an oil-flotation plant and a vigorous campaign of underground development have recently brought production to a higher level than previously attained.

Preceding these recent developments, a geological examination of the deposit was made by Mr. H. W. Turner, and specimens which he collected were studied microscopically by Prof. A. F. Rogers, of Stanford University. The results of their investigations, published as a joint paper in this journal,[2] merit particular attention because of the two principal conclusions which the authors reach, viz.: (1) that the ores are of direct magmatic origin, and (2) that the development of chalcocite and some covellite by replacement of bornite is the work of ascending, heated alkaline waters and is thus to be regarded as an example of "upward secondary enrichment."

The accelerating tendency in recent years to ascribe the origin of many ore deposits to igneous influences must be admitted to rest more on reasonable inference and on elimination of objections than upon direct and positive evidence. Any instance in which sulphide ores have been formed in syngenetic relation to the enclosing igneous rock therefore assumes special interest and significance. The importance thus given to the Engels occurrence

[2] Vol. 9, pp. 359–391 (June, 1914).

was only increased by a paper by T. T. Read,[3] who, after a brief visit to the deposit, concluded that the magmatic origin of the ores is not certain.

Still more interest, if possible, attaches to the Engels deposit in connection with the origin of the chalcocite. The idea of "upward secondary enrichment," though it had been earlier hinted at or somewhat vaguely invoked to explain certain observations, was proposed as a definite hypothesis for copper sulphide ores in an earlier paper[4] by Professor Rogers. That paper was virtually an announcement of the hypothesis and an application of it to the deposits of Butte, in advance of the complete description of an unnamed occurrence which, in Professor Rogers's opinion, afforded the most convincing proof of the hypothesis. This hypothesis was immediately accepted and adopted by the corps of able and assiduous investigators at Stanford and has already been given by them a conspicuous place in the literature. Among interested students elsewhere, the expected article by Professor Rogers that should deal with specific evidence of upward secondary enrichment in a carefully studied example was awaited with interest; it proved to be the paper on the Engels mine.

The distinction between ascending and descending influences for the formation of chalcocite by replacement of other sulphides, is of course of more than academic interest because of the predominant part which the mineral plays in the world's supply of copper. The general assumption now is that most chalcocite is due to descending enrichment; in consequence, operations and plans, whether mining, metallurgical, or financial, are based more or less directly on the expectation that at some depth, commonly not very great, below the surface, the commercial supply of this mineral will cease. If, however, it can be shown in any instance that the formation of chalcocite is independent of surface influences but is instead the result of agencies ascending from deep-seated sources, then it becomes evident that precautions and plans based on the ideas of superficial origin and shallow extent

[3] *Mining and Scientific Press*, July 31, 1915, pp. 167–171.

[4] ECON. GEOL., Vol. 8, pp. 781–794, Dec., 1913.

of the commercial ore may be baseless and may prove both costly and inefficient.

Actuated by the interest arising from Turner and Rogers's very suggestive description, one of the authors of the present paper found opportunity to make a brief visit to the Engels deposit in September, 1915, spending a day and a half at the mine. In the course of the laboratory study of the materials collected, we arrived at conclusions sufficiently at variance with those recorded by Messrs. Turner and Rogers as to seem to justify publication of our findings. Certain questions, however, that arose, particularly with regard to structural features of the deposit, made it advisable to revisit the occurrence. In June, 1916, the other author spent two days at the mine, and was thus afforded opportunity to secure the data in question, to make further observations and collect additional specimens from the latest as well as some of the earlier workings, to test on the ground the conclusions already reached, and to make a brief inspection of the nearby Superior deposit which is also owned by the Engels Company.

In the meantime, Professor Rogers had somewhat revised his first ideas, especially in recognizing that part of the Engels chalcocite is due to the normal process of descending enrichment. In consequence, some of our evidence upon this important point is merely confirmatory, as is indeed the case with regard to many of the other matters discussed. There remains, however, sufficient divergence of views as in our opinion to warrant presentation of all our evidence.

With regard to the two principal questions involved in the Engels occurrence, we conclude as follows:

1. The ores, instead of being magmatic in the sense that they were initial constituents of the dioritic rock in which they occur, were introduced after the rock had solidified and had suffered notable dynamic and chemical changes, and constitute replacements formed under pneumatolytic and hydrothermal conditions. The deposition of the sulphides was an intermediate episode in a complex and unusually complete sequence of magmatic phenom-

ena and after-effects that began with crystallization of the parent rock and ended with the formation of zeolites and carbonates.

2. Although the possibility of formation of a small amount of chalcocite from ascending solutions cannot be absolutely excluded, no satisfactory evidence of chalcocite of replacement origin formed in this way, *i. e.*, by "upward secondary enrichment," has come under our observation. Most of the chalcocite and all of the covellite at Engels unquestionably result from replacement of earlier sulphides through the agency of descending meteoric waters, and a competent explanation for *all* of the chalcocite is to be found in normal downward enrichment.

The conclusions and indeed all parts of this paper, unless otherwise stated for specific cases, are to be understood as applying solely to the particular deposits that are the object of this inquiry and as carrying no implication as to other districts in which the work of the Secondary Enrichment Investigation has been pursued.

Inasmuch as the terms "primary," "secondary," and "secondary enrichment" in the senses in which they are commonly used have been severely criticized by Professor Rogers, and inasmuch as in our discussions it has been necessary to refer frequently to Rogers's results in his own terms and to differentiate his findings from ours, we have decided that it would be wise in this particular case, and we have endeavored, in consequence, to express our meaning by the use of terms which we hope can be misunderstood by no one, notwithstanding our conviction that the usual terminology is well established and accurately understood by the great majority of readers of geological literature.

We desire to express our indebtedness to Mr. Edmund Juessen, formerly in charge of operations at the Engels Mine and to Mr. John Reinmiller, mine superintendent, for information and guidance which they courteously gave us, and our thanks to Professor J. E. Wolff for helpful petrographical criticism, and to Mr. W. L. Whitehead who made for us one of the microphotographs which accompany this paper.

GENERAL DESCRIPTIVE TREATMENT—COUNTRY ROCK, ORES, AND ALTERATION.

Magmatic Period.

Solidification of Norite.—The Engels ore-deposit occurs in a body of rather dark, medium-grained plutonic rock, which is probably a basic differentiate of the great Sierra Nevada batholith of granodiorite. The rock was nowhere seen in its original condition, but it may confidently be inferred from its altered phases that it was noritic in character, being composed of plagioclase and slightly subordinate amounts of orthorhombic and monoclinic pyroxenes, and biotite. The feldspar varies somewhat in character, but usually it is near an acid labradorite in composition (Ab_1, An_1). Bronzite, hypersthene, and diopside are present in quantity that approximately equals the feldspar, while the biotite is usually subordinate in amount, although its small laths are occasionally plentiful. Zircon, apatite and euhedral magnetite are common accessories.

The form of the body of norite is not definitely known, as surface croppings are scarce, and its contacts with the surrounding rock of the batholith can not be traced. Underground, on several levels, in passing out of the ore, siliceous rocks are encountered, which possibly mark the limits of the norite body in those directions. In a cross-cut off Tunnel 4, one of these light-colored, acidic rocks is encountered, and proves to be a granodiorite porphyry. The rock is characterized by large feldspar phenocrysts, set in a medium to fine grained ground-mass, consisting chiefly of unstriated feldspar and biotite. Under the microscope, the "phenocrysts" are seen to be composite, consisting of aggregates of smaller laths of andesine, of about the same grain as the constituents of the ground-mass (Figs. 1 and 2). The ground-mass is chiefly orthoclase, quartz and biotite with an accessory amount of plagioclase. This somewhat acid rock may reasonably be interpreted as another variant of the granodiorite batholith but of subordinate importance.

Pneumatolytic Period.

Alteration of Norite.—After the crystallization of the norite, a period ensued in which conditions of equilibrium were apparently disturbed, probably by increasing concentration of water and other mineralizers; this may be termed the pneumatolytic period. The magmatic products were partially altered into minerals more stable under the new conditions; chief among these is amphibole, formed in part at the expense of the pyroxenes, while the labradorite underwent partial recrystallization with attendant cracking and straining, and the production of rims of more acidic varieties, oligoclase and albite. The resulting rock may be regarded as a peculiar type of diorite, or perhaps more properly as a meta-norite. This derivative of the original norite is more extensive than the ore-bodies and constitutes the principal country rock of the Engels mine. The amphibole is chiefly a light green hornblende, but locally, along seams and in segregations, laths of actinolite were formed. The hornblende is widely developed throughout the rock, but it is more abundant and in largest crystals in the ore-bearing portions. It forms large, strikingly poikilitic crystals, frequently containing corroded cores of pyroxene, but extending far beyond the original limits of the pyroxene crystals, and including numerous rounded grains of labradorite and small particles of the accessory minerals (apatite and magnetite). Slightly corroded laths of biotite are frequently included in the large crystals. In many cases, the inclusions are so abundant that their total volume is considerably greater than that of the amphibole host.

Formation of Segregations.—The formation of small lens-shaped segregations in the norite (or diorite) is clearly related to this period of pneumatolytic alteration. They probably represent the products of the late crystallization of small localized concentrations or residues after the crystallization of the normal magmatic minerals. In these segregations, actinolite and albite are the chief minerals, although in a few cases, biotite assumes an equal importance. In one interesting occurrence, a lenticular mass, over eight inches in diameter and approximately two inches

EXPLANATION OF PLATE I.

Photographs of thin sections from the Engels Mine, Plumas Co., California.

FIG. 1. (× 10 diameters.) Feldspar phenocrysts in granodiorite porphyry.

FIG. 2. (× 15 diameters.) Same as Fig. 1, but with crossed nicols, showing recrystalliization of the phenocrysts.

FIG. 3. (× 68 diameters.) Crossed nicols. Broken apatite prism in strained feldspar.

FIG. 4. (× 15 diameters.) Bornite (black) replacing rock-minerals, with only slight development of chlorite and epidote.

FIG. 5. (× 38 diameters.) Hornblende crystals containing small inclusions of magnetite and spinel (*spn.*), and corroded by surrounding magnetite. Note abundant inclusions of apatite in the magnetite, and the occurrence of bornite in ragged grains with chlorite.

FIG. 6. (× 50 diameters.) Bornite and chlorite replacing amphibole. Magnetite in smoother grains.

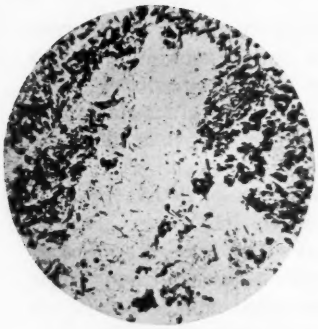


FIG. 1.

FIG. 2.

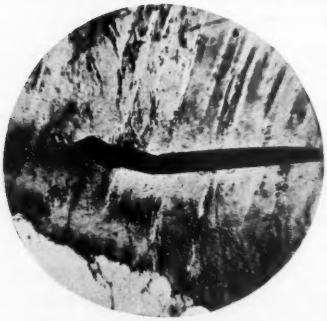


FIG. 3.

FIG. 4.

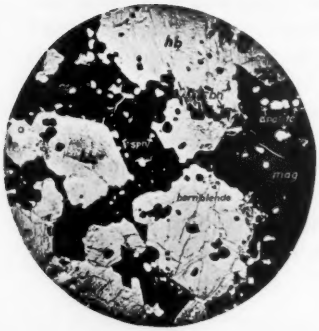


FIG. 5.

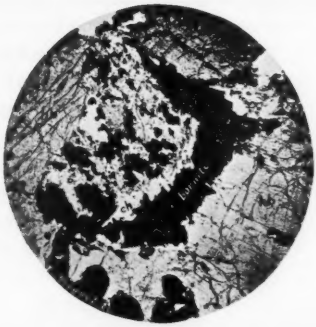


FIG. 6.

thick, occurs in the fine-grained dioritic rock. The outer layer of this segregation consists of stubby, green laths of actinolite, and it is succeeded inward by a well-marked zone of albite, in coarse anhedra. This in turn surrounds an inner core which was originally an aggregate of actinolite, albite and large crystals of titanite. In this and in most of the other segregations studied, the cores and frequently the outer layers are largely replaced by chlorite, epidote and calcite, with associated copper ores, but these changes are clearly subsequent to the formation of the segregations themselves. The amphibole is always earlier than the albite, the latter being molded about the well-formed prisms of the former in many cases, but it is later than the biotite, except that locally, where the biotite is especially abundant in a segregation, the order may be reversed.

Formation of Pegmatites.—In a few places underground, the workings expose narrow pegmatite dikes cutting the diorite. They are composed chiefly of acid feldspar and subordinate quartz, with a small amount of actinolite, usually concentrated near the edges or developed in the adjoining wall rock. Chalcopyrite, but rarely bornite, is associated with the pegmatites, as intermittent central bands, or as disseminated grains in the neighboring diorite. In one specimen from a one-inch dike exposed in a drift to the northeast off Tunnel 4, microscopic examination shows the feldspar to be albite-oligoclase, with small cores of a more basic type. With it are pale green laths of actinolite, with subordinate amounts of quartz, titanite, and apatite. A persistent band of chalcopyrite along the center of the dike is the only sulphide in this case. In another specimen from a larger dike, the pegmatite was found to be composed of quartz, microcline, and small amounts of labradorite, titanite, and a deeply pleochroic hornblende, with a few crystals of tourmaline. Patches of chalcopyrite and bornite occur in it, and appear to be original constituents.

Dynamic Changes.—A pronounced straining and shearing of the feldspars, accompanied by recrystallization in various degrees, is notable throughout the rocks studied. In many cases, no traces of these changes are found in the large amphibole crystals, al-

though the surrounding and included feldspars show wavy extinction (see Fig. 3) and partial granulation. In other cases, the amphibole itself may lose its fresh, coarse-grained character, and become reduced to shreddy masses of variously oriented fibers, often distinctly uralitic in appearance. It may therefore be inferred that the straining and accompanying recrystallization took place within the pneumatolytic period, although locally it may have continued longer, or even have started somewhat later. The recrystallization is not confined to the diorite, but is also well shown in the neighboring siliceous rocks. An excellent example is the breaking down of the phenocrysts of the granodiorite porphyry into an aggregate of andesine crystals, as is clearly shown in the two photographs (Figs. 1 and 2). In several of the specimens, a distinct schistose structure has been produced by the grouping of the recrystallized biotite laths in bands. The feldspar assumes a crystalloblastic texture in these cases, but the grains of the pyroxenes show little change. Where the recrystallization is most intense, apatite is abundant, forming elongated clusters of rounded grains of distinctly different habit from the ordinary magmatic apatite. In one or two slides, a subparallel arrangement of plagioclase laths may be attributed to the flowage of the partially crystallized magma, but superimposed on this structure are changes similar to those previously described, which can be satisfactorily explained only as the result of stresses acting on the rigid rock. The fractured apatite crystal in Fig. 3 is striking evidence of dynamic action.

Development of Iron Oxides.—Associated with the more intense phases of the development of the amphibole, but for the most part a little later, is magnetite, in large masses with abundant inclusions of apatite. This iron ore is clearly later than the small euhedral grains of magnetite, accessory in the norite, which were included by the growing crystals of the pneumatolytic hornblende. The later magnetite occurs commonly molded about the amphibole forms, occasionally slightly corroding them, and in a few cases it is so abundant that the crystals of hornblende appear as if set in a cement of magnetite and apatite, with a relatively subordinate amount of rounded feldspar grains and

a little spinel (see Fig. 5). The pneumatolytic origin of this magnetite is indicated by its close relationship with the development of the amphibole, and this view is confirmed by the abundant apatite and by the occurrence in several instances of small crystals of tourmaline in close association with the magnetite.

With the magnetite, and perhaps in part a little later in origin, occur ilmenite and hematite. Intergrowths of all three minerals have been observed, while those of ilmenite and hematite are very common, occurring in nearly all of the polished chips studied. In these intergrowths the hematite is usually subordinate, and appears most commonly on the polished surface as fine white lines, in parallel orientation in one, or more rarely, two directions. Other sections show the hematite as elongated, narrow ovals or as dots scattered with a rough regularity through the ilmenite. The magnetite occasionally contains plates of hematite, and now and then occurs in rather patchy inclusions in ilmenite-hematite areas, the fine white lines of hematite passing uninterruptedly through the magnetite as well as the ilmenite. These minerals were determined by mineralographic methods,[5] and the presence of ilmenite was confirmed by obtaining titanium tests from gravity concentrates from the crushed specimens.

Development of Pneumatolytic Sulphides.—The most important phase of mineralization, as far as the value of the ore is concerned, is that which is characterized by the development of chalcopyrite and bornite. In most cases, these sulphide ores are accompanied by notable hydrothermal alteration of their host and are therefore described under a subsequent heading, but in a few specimens, they occur in remarkably fresh feldspathic rock. They are clearly later than the rock minerals, which they surround and slightly corrode, and are in places so abundant that the rounded grains of plagioclase and laths of biotite appear as if set in an opaque cement (Fig. 4). In relative smoothness of outline, the sulphide grains resemble those of magnetite. These sulphides seem to be analogous to the ores in the pegmatite, previously mentioned, and are regarded as the earliest in origin

[5] Murdoch, J., "Microscopical Determination of the Opaque Minerals." Wiley & Sons, 1916.

which we have observed. The structure might readily suggest a magmatic origin for the chalcopyrite and bornite, but, on more careful examination, occasional laths of chlorite and sericite may be seen included in the sulphide grains, and, where the sulphides are in contact with the plagioclase, thin borders of albite are found. In the material which best exhibits these relations, the bornite occurs as definite seams, near which the impregnation of the rock with ore is greatest. Along these seams the rock readily breaks apart, yielding fracture faces completely coated with bornite.

This pneumatolytic stage is the nearest approach to magmatic conditions that is shown by the development of the sulphides, for the earlier minerals such as the labradorite and biotite remain fairly resistant to the introduced material, but the presence of the hydrothermal minerals, and the fracturing of the rock, indicate that strictly magmatic conditions had passed.

Intense Hydrothermal Period.

Development of Chlorite, Sericite and Epidote.—The commonest type of sulphide ore, however, is indicative of slightly milder conditions than those of the pneumatolytic period just described. Chlorite, sericite, epidote and calcite become more and more important. The chlorite is especially characteristic, occurring as blunt laths or slivers included in the bornite or chalcopyrite, or occasionally as complicated tangles of small laths, with the sulphides both as acutely angular areas between them and as thin wedges extending along the cleavage of the chlorite. Rogers first regarded the chlorite as earlier than the bornite but in his later paper he states that the chlorite is younger than the bornite and replaces it. Our evidence is in essential accord with the first view and we are unable to follow Rogers's argument in favor of the second. In some cases, the bornite distinctly corrodes the chlorite laths (Fig. 12). Moreover, it is generally true that the direction of the chlorite laths is not in accord with the structure of the bornite as revealed by natural alteration or by etching. On the other hand, many of the laths appear unattacked, and

probably are virtually contemporaneous with the bornite. The chlorite was frequently found between the magnetite individuals, some of which are well crystallized (Figs. 7 and 8); it was never observed as inclusions in the magnetite. The biotite is partially or completely replaced by chlorite, especially where the latter is well developed with the ores. The amphibole also suffered a partial alteration to chlorite, and in many cases amphibole crystals are fringed with ragged borders of chlorite and bornite, or are penetrated by veinlets of these two minerals. The large hornblende crystals in Fig. 7 well illustrate this type of alteration.

The sericite is largely confined to the basic plagioclase, but occasionally it is more widely developed, and bears a relation to the bornite very similar to that shown by the chlorite. Fine laths and slivers of sericite are included in the bornite or chalcopyrite, usually near the edges, less commonly in the heart of the grains. In both of Rogers's papers, the sericite laths penetrating the bornite are regarded as having replaced the sulphide, but we have failed to find evidence supporting this view. It seems to be much more in accord with the usual criteria of sequence to regard them, like the chlorite, as inclusions in the bornite. Apparently the bornite and the sericite developed at about the same time; the bornite commonly started first, accounting for the usual absence of sericite in the cores, but toward the edges of the grains, the sericite formed as laths a little ahead of the last outermost parts of the bornite, in which they are therefore included. Sericite is not abundant in specimens which on other grounds are regarded as examples of the earliest sulphides, and this is in accord with the view just expressed. The basic feldspars are most thoroughly altered to sericite, while the more acid rims or recrystallized portions usually remain untouched. The biotite is slightly attacked by the sericite, but to a greater extent it is altered to chlorite, as is conclusively shown by the presence of residual sagenite webs in certain large areas of chlorite. In a few instances, the lath-shaped inclusions of chlorite and sericite in the ores may likewise have been derived from corroded biotite or remnants of amphibole, but this explanation will not hold for the majority of cases

EXPLANATION OF PLATE II.

Photographs of thin sections from the Engels Mine, Plumas Co., California.

FIG. 7. (×49 diameters.) Hornblende crystal surrounded by magnetite and corroded by chlorite and bornite. Chlorite also in thin foils between magnetite grains.

FIG. 8. (×38 diameters.) Magnetite and bornite with chlorite along boundaries.

FIG. 9. (×23 diameters.) Euhedral epidote crystals included in bornite.

FIG. 10. (×39 diameters.) Crossed nicols. Plagioclase partially replaced by heulandite (*heu.*), and both partially altered to natrolite.

FIG. 7.

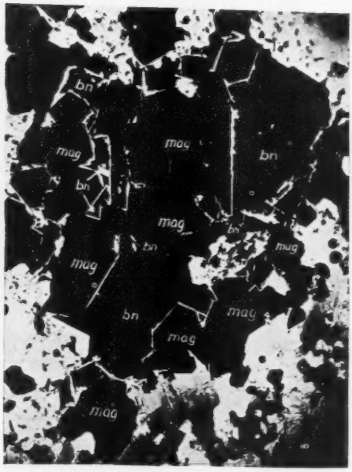


FIG. 8.

FIG. 9.

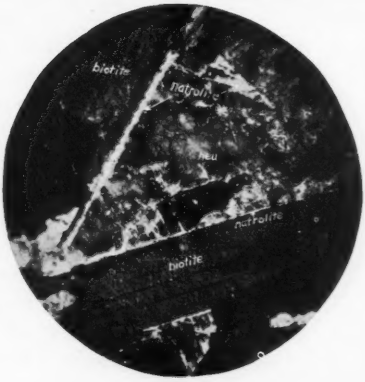
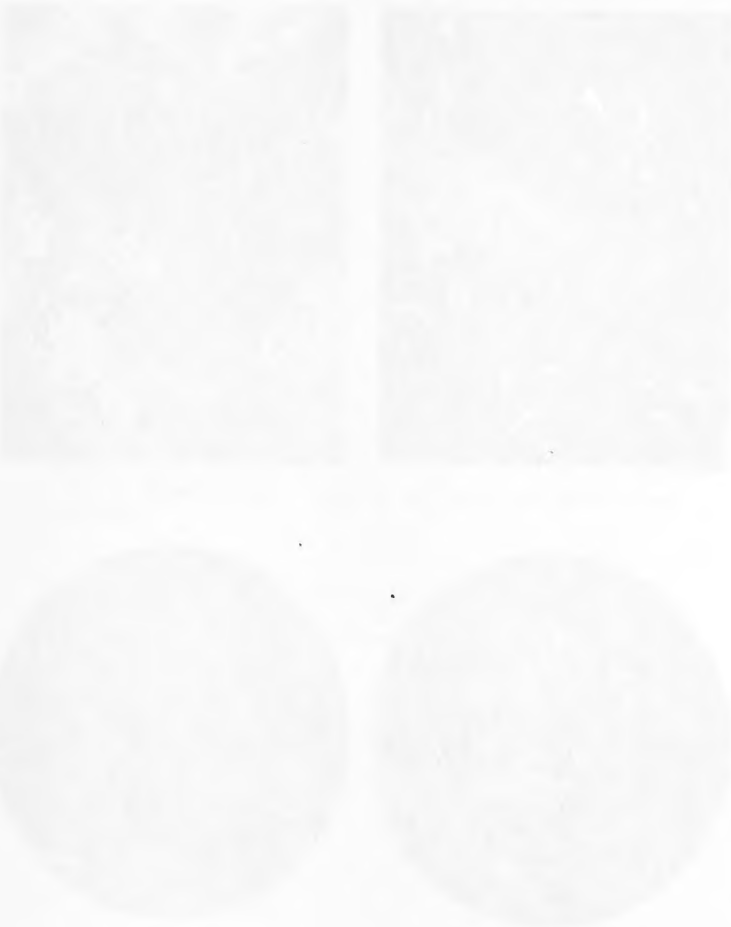


FIG. 10.



since the inclusions are in general distinctly different in habit from the original brown biotite or the amphibole of the rock. Although it is impossible to reach a positive conclusion concerning the relative ages of the chlorite and sericite, there is a suggestion that part of the chlorite is a little older than the sericite, for the kind of corrosion by bornite shown by chlorite laths has not been certainly observed in the case of the sericite; also the chlorite is less noticeably confined to the outer margins of the bornite grains than is the sericite.

Epidote is also a common associate of the sulphides. In some cases veinlets of it cut chlorite (Fig. 11), but for the most part the two minerals are apparently contemporaneous. The epidote may form fringes about grains of bornite and chalcopyrite; elsewhere it occurs in euhedral forms about which the sulphides are molded (Fig. 9). In many places, the amphibole is greatly altered to epidote, and veinlets or irregular patches of the latter are common as replacements in the feldspars. A few veinlets have been observed cutting magnetite. Ragged areas of fine-grained epidote, thickly filled with small grains of bornite or chalcopyrite, and with more or less chlorite are found here and there in greatly altered specimens.

Development of Hydrothermal Sulphides.—The commercial ore at Engels is distributed in somewhat indefinitely-bounded shoots, of which several have been opened and which collectively constitute a deposit of roughly elliptical plan within the modified norite. As a rule the ore merges into the country rock and all gradations exist from scattered minute sulphide grains to heavy masses of ore with subordinate gangue.

The bornite and chalcopyrite, which are the most abundant ore minerals of the Engels deposit, were formed mainly under hydrothermal conditions, together with a small amount of enargite, tetrahedrite and sphalerite. Magnetite, ilmenite and hematite, which apparently had continued to develop during the early portion of the period of bornite formation, ceased to form as conditions became milder, and became surrounded or rarely veined by the bornite and chalcopyrite which continued to in-

EXPLANATION OF PLATE III.

Micro-photographs of ores from the Engels Mine, Plumas Co., California.

FIG. 11. (×34 diameters.) Thin section. Epidote veinlets cutting albite and chlorite. Also patches of epidote.

FIG. 12. (×500 diameters.) Polished surface. Chlorite lath corroded by bornite.

FIG. 13. (×54 diameters.) Polished surface. Chalcopyrite (light) and bornite (dark) with "mutual boundaries." Gangue, black.

FIG. 14. (×54 diameters.) Polished surface. Bornite grains (dark) with chalcocite rims (light) associated with gangue (black). Note early stages of lattice structure developed by small chalcocite tongues in the bornite.

FIG. 15. (×661 diameters.) Polished surface. Lattice structure developed in bornite (*bn*) by chalcopyrite spines (*cp*) with chalcocite rims (*cc*). (Photograph by W. L. Whitehead.)

FIG. 16. (×62 diameters.) Veinlets and patches of chalcocite (light) in bornite (dark) in part along gangue veinlets (black).

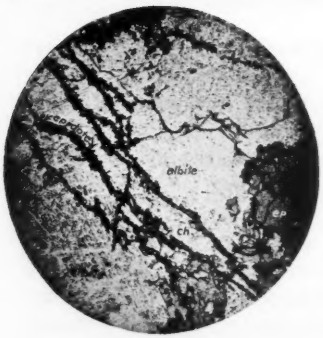


FIG. 11.

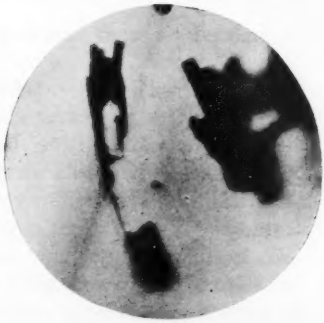


FIG. 12.

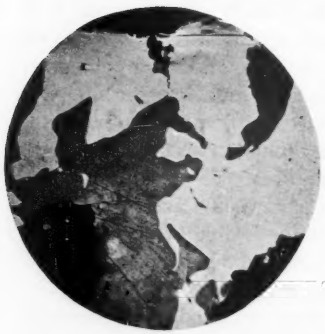


FIG. 13.

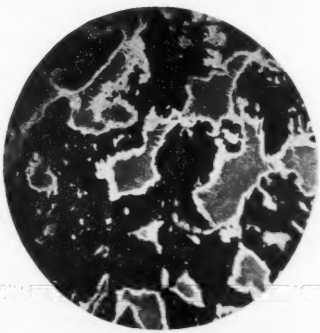


FIG. 14.

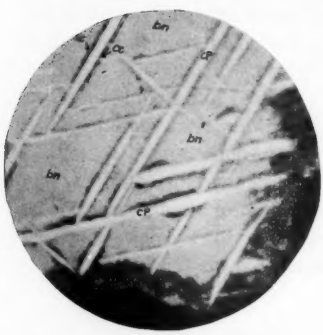


FIG. 15.

FIG. 16.

crease. The bornite is about three or four times as abundant as the chalcopyrite.

For the most part, the contacts between the chalcopyrite and bornite offer little evidence of the sequence of the two minerals. Broad bays of chalcopyrite extend into the bornite or smooth projections of the bornite penetrate the chalcopyrite, but in many cases if the forms of two minerals were interchanged, their relations to each other would be little altered. The term *mutual boundary* has been found useful in referring to the line of contact of minerals in this association (Fig. 13). There is evidence, however, that the chalcopyrite slightly preceded the bornite, as inclusions of the former are commoner in the latter than the reverse, even where the two sulphides occur in equal amounts, and in a few cases the chalcopyrite shows slight corrosion by the bornite. Nevertheless, for the greater part of their periods of formation, they were probably contemporaneous.

As the proportion of the chlorite and epidote grows, indicating increased departure from magmatic conditions, the ores become more and more ragged and irregular, and in the thin section are easily distinguished by their form alone from the more regular magnetite grains. They seem also to have exerted a greater corrosive action on the rock minerals, the amphibole especially suffering, although the other constituents are not spared.

The enargite occurs sparingly with the other sulphides, and is apparently of about the same age. Tetrahedrite is perhaps a little commoner and its presence may account for the slight silver value of the ore. It occurs in the same relationship to the bornite and chalcopyrite as the enargite. A few minute grains occurring in hornblende were identified as galena.

Calcite is abundant in most of the specimens. It clearly replaces amphibole and feldspar, and is associated with the epidote in an intimate way, veinlets of each cutting the other. The calcite had a longer range, however, extending into the period of later hydrothermal conditions. Rogers mentions finding calcite as a late magmatic mineral. In our thin sections, the calcite is clearly a replacement of earlier minerals, although in certain areas the replacement is so complete that, if evidence from other

portions of the slide had not revealed its true character, it might have been mistaken for an earlier constituent of the rock. In no case, however, was there the least doubt of its distinctly later character.

Late Hydrothermal Period.

Development of Zeolites and Carbonates.—One of the most interesting phases of the rock alteration is the development with the carbonates of a series of zeolites, as a late hydrothermal product. The following members of the group were definitely determined, by means both of thin sections and of index liquids: scolesite, analcite, heulandite, natrolite, and laumontite. Thin radial aggregates of thomsonite and small patches probably of chabazite and phillipsite were identified in thin sections only, but the minerals are not present in sufficient quantities to permit of their determination with absolute certainty. A little prehnite, found in only one section, is probably a product of the same conditions as the zeolites. The minerals of the zeolite group are fairly widespread, occurring in over one third of the specimens studied.

In one specimen, scolesite has completely replaced the plagioclase, whose former presence is indicated only by the zeolite-filled molds of magnetite, which had shaped themselves about the original feldspar laths. A surprising feature is the presence of unaltered hypersthene, bronzite and diopside in this greatly altered rock; having apparently escaped the alteration to amphibole in the pneumatolytic period, the pyroxenes remained resistant to the zeolitizing conditions. The scolesite also forms a veinlet half an inch wide of finely radial, white fibers, and in it are a few grains of bornite, which show the feeble extension of the bornite forming conditions into the period of the zeolites.

The commonest type of zeolitic alteration is the replacement of feldspar by heulandite, and in about half of the cases, the subsequent replacement of the heulandite by natrolite. The analcite in the rocks was observed by Rogers, who regarded it as a primary constituent. In one or two instances, it occurs as shapeless grains, which give no clue to their origin, but in other

cases it seems unquestionably to be a replacement of feldspar, and its association with the other zeolites confirms this view. Calcite or siderite is usually present, replacing even the latest zeolites, although occasionally they are themselves cut by veinlets of natrolite.

Our evidence is not sufficient to permit the entire list of zeolites observed to be grouped in the precise order of their formation, but the analcite and heulandite are clearly earliest, with natrolite, laumontite, and thomsonite forming a later group. The relative positions of the others are in doubt. The carbonates are persistent, and in many places the completeness with which they replace the preceding minerals has greatly obscured the evidence of the earlier relationships. Siderite is less common than calcite, but it is frequently found as a border about calcite grains, being readily distinguished by its much higher relief, better crystal form, and slight iron staining where exposed to oxidation. It is not established with certainty, however, that the siderite is a member of this mineral group formed under late hydrothermal conditions; the possibility that it is a product of descending oxidizing solutions will be considered later.

Period of Oxidation and Enrichment.

Between the period of the formation of the zeolites and the exposure of the ore to the influence of oxidation, the ore-bearing rock was again broken by series of roughly parallel cracks, which became filled with fine veinlets of siderite and calcite. The breaks are abundant in certain zones, and almost lacking in others. They show no relation to the earlier shearing and straining of the rock. All minerals and structures previously described are broken by them, except that they show a marked avoidance of bornite grains which lie in their paths. Occasional carbonate veinlets cut through the bornite, but far more commonly they are diverted, and pass around the border of the sulphide grains. On the other hand, the magnetite and ilmenite-hematite intergrowths are greatly cracked, as if they were more brittle, and are penetrated by the veinlets wherever these are notably developed. The earlier shearing and recrystallization of the rock,

and the later fractures occupied by veinlets were of great importance in facilitating the downward movement of surface solutions by which oxidation and descending secondary enrichment were accomplished.

Zone of Complete Oxidation.—The outcrop of the Engels deposit, which lies at an elevation of about 5,500 feet, is wholly inconspicuous. A mantle of granular soil conceals the rock except at a few places where slightly copper-stained croppings are exposed but do not project noticeably above their surroundings. The orebody is capped by a moderate but irregular thickness of oxidized and leached rock. Plainly this material once contained sulphides for it is stained by limonite, malachite and chrysocolla, and is cut by banded seams and small veins of these minerals. In these veinlets, the silicate seems to have been the last to form, frequently breaking across the carbonate bands, and building out as knobby, botryoidal forms into open spaces presumably formed by removal of the sulphides.

Zone of Sulphide Enrichment.—According to Mr. Juessen, who was in charge when the upper parts of the orebodies were developed, the zone of complete oxidation changes irregularly into a zone of mixed carbonate and chalcocite ore, rich portions of which were mined, but caving has made these uppermost stopes now inaccessible. This was succeeded immediately below by a much more definite and regular zone of chalcocite ore, of which much the largest and richest portions were discovered subsequent to the examination made by Mr. Turner. Ore of this kind was found in a locus averaging about twenty-five feet thick, and dipping approximately parallel to the surface, which slopes rather gently to the southwest. A very considerable tonnage of such chalcocite ore was mined out, with values up to 16 per cent. copper, and an average grade materially higher than that of the ore at greater depth. In general, this ore gradually fingered out at depths of about 90 to 130 feet below the outcrop into ore consisting essentially of bornite, but occasional stringers and bunches of chalcocite ore extend considerably deeper.

In nearly all the chips studied, chalcocite was found in varying amounts, commonly as a replacement of bornite and to a very

small extent a replacement of chalcopyrite. Its most striking development is in connection with the veinlets of carbonate previously discussed, and this relationship persists to the deepest workings of the mine (June, 1916), a winze 125 feet below the level of No. 4 Tunnel or about 375 feet from the surface. In many cases chalcocite occurs only where the bornite is broken or bounded by such veinlets. The abrupt manner in which laths of sericite are cut by the veinlets with which the chalcocite is associated, leaves no doubt of the independence of origin of the chalcocite from the sericite. Veinlets of chalcocite are frequently observed to take advantage of the presence of included laths of chlorite or sericite along their course, breaking from one to another, while other laths nearby, but not intercepted by the veinlets, may be sharply bounded by the bornite without a trace of chalcocite. Where the bornite occurs in small ragged slivers in aggregates of epidote, chlorite or sericite, the enrichment is most complete, due both to the greater permeability of the rock at such places, and to the relatively greater surface of bornite exposed by the finer grains. Chalcocite is commonly well developed also where the bornite is penetrated by laths of chlorite or sericite, although occasionally no enrichment is observed in connection with these minerals. Our studies of chalcocite formation in many districts indicate that enrichment favors the contacts between primary sulphides and gangue minerals (Fig. 14), because of the greater local permeability along these junctions, and that micaceous gangue minerals, as sericite or chlorite, notably promote both local and general enrichment, as Beeson has so clearly shown in the case of Bingham.[6]

In addition to the replacement of bornite along irregular veinlets and grain boundaries, the chalcocite also replaces that mineral along crystallographic planes. Where this type of replacement is well developed, the polished surface reveals a strikingly regular pattern, consisting of three intersecting systems of narrow strips of chalcocite, separated by triangular and rhombic residues of the bornite; this well-known relationship may be termed the *lattice structure.*

[6] Beeson, J. J. Bull. A. I. M. E., No. 107, Nov. 1915, p. 2228.

EXPLANATION OF PLATE IV.

Photographs of polished surfaces of ores from the Engels district, Plumas Co., California.

FIG. 17. (× 53 diameters.) Engels Mine. Bornite (dark) and chalcocite (light) in graphic structures. Gangue, black.

FIG. 18. (× 190 diameters.) Engels Mine. Chalcocite (light) in graphic structure with the bornite (dark), and along gangue contacts in bornite. Enlargement of a portion of the field of Fig. 17.

FIG. 19. (×53 diameters.) Superior Mine. Bornite (dark) with chalcocite (light) in graphic structure. Small magnetite grains (with black rim indicating high relief).

FIG. 20. (× 211 diameters.) Engels Mine. Chalcocite (light) in graphic structure, near edge of bornite grain (dark), and associated with chalcocite in veinlets in the bornite and along gangue contact.

FIG. 21. (× 53 diameters.) Superior Mine. Magnetite grains (showing high relief) surrounded by bornite (dark) containing chalcocite (light) in the graphic structure. Chlorite laths (black) in the bornite-chalcocite areas. Note that the chalcocite is independent of the included laths and of the magnetite-bornite contacts.

FIG. 22. (× 53 diameters.) Superior Mine. Magnetite crystals (shown by high relief) surrounded by bornite (dark) containing blebs of chalcocite (light) suggesting imperfect graphic structures.

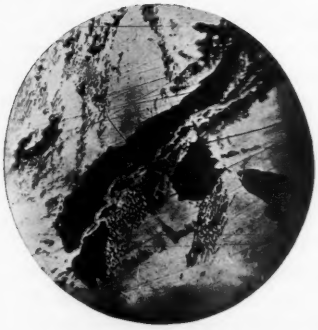


FIG. 17.

FIG. 18.

FIG. 19.

FIG. 20.

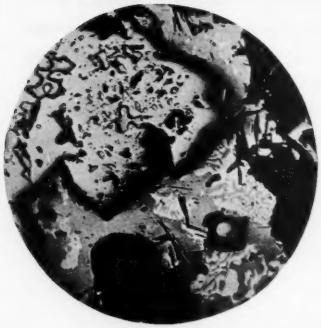


FIG. 21.

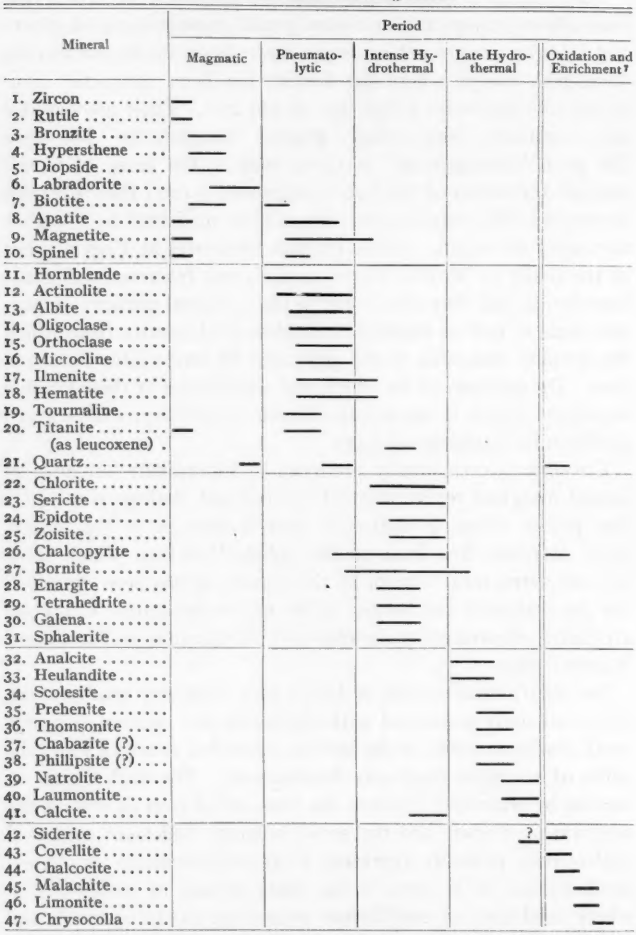
FIG. 22.

Associations of bornite and chalcocite in minute structures that resemble micropegmatitic or micrographic intergrowths of quartz and feldspar are present sparingly throughout the deposit as now developed, except where the bornite has been completely converted into chalcocite (Figs. 17, 18 and 20). These associations have commonly been called "graphic intergrowths" but since the word "intergrowth" is often used in the sense of simultaneous formation of the two components, a term that is merely descriptive, like *graphic structure,* is to be preferred as it implies no theory of origin. These graphic structures at Engels occur in the midst of bornite masses away from fractures and grain boundaries, and they also occur in the marginal portions of bornite areas as well as adjacent to veinlets of chalcocite from which the graphic chalcocite is not separated by any visible demarcation. The question of the origin and significance of these graphic structures, which is one of considerable complexity, will be given attention on a subsequent page.

Covellite is occasionally produced in subordinate amounts by partial marginal replacement of bornite and chalcopyrite. In a few places, either in chalcocite near bornite or in the bornite itself, it forms fine lines on the polished surface, which show the same structural control by the bornite as has been described for the chalcocite and bornite in the lattice structure. Examples are clearly illustrated by sketches and photographs in Turner and Rogers's paper.

Secondary chalcopyrite is found to a relatively small extent. It is commonly associated with chalcocite, but appears to prefer small cracks or nooks in the bornite somewhat removed from the paths of strongest chalcocite development. The replacement of bornite by chalcocite involves the removal of iron as well as the addition of copper, and the small isolated veinlets or spines of chalcopyrite probably represent local concentrations of iron—small eddies, as it were, in the main stream of enrichment—where conditions of equilibrium were temporarily reversed, and the iron-rich sulphide formed. The chalcopyrite frequently penetrates the bornite along definite structural lines, producing in some cases a lattice pattern similar to that described for chalco-

DIAGRAM OF MINERAL SEQUENCE.



[7] The indications of sequence given under the period of oxidation and enrichment are intended to show the progressive arrival of various influences at any given horizon. In reality, probably all the minerals of the period have been forming, at one part or another of the deposit, from the beginning of oxidation to the present.

cite and for covellite in bornite (Fig. 15). Inasmuch as various stages have been observed from a few isolated spines penetrating the bornite from the edge of a veinlet of chalcocite due to downward enrichment to the well-developed lattice-work, there can be no doubt that these chalcopyrite spines are of the same origin as the chalcocite. In the specimen which shows the most striking development of secondary chalcopyrite, the high concentration of iron and the influence of surficial conditions are indicated by the development of a strong seam of limonite, to which the distribution of the chalcopyrite shows a definite relationship.

DISCUSSION.

Genetic Classification of the Deposit.

The grouping of the minerals (p. 24) is merely a summary of the interpretation of the genesis of the deposit presented on the preceding pages, and so needs little further discussion. The magmatic group includes only the minerals which crystallized directly from the differentiated magma. As the separation of the normal rock-forming constituents became more and more complete, the concentration of volatile constituents in the residual magmatic material steadily increased, and conditions of normal magmatic crystallization gradually changed to those in which pneumatolytic processes played the dominant part. The widespread alteration of pyroxene to amphibole, the formation of tourmaline, the small lenticular segregations and dikes of pegmatitic nature are attributed to this phase. Following this type of alteration, changes of distinctly hydrothermal character were imposed upon the rock, differentiated from the preceding pneumatolytic conditions by the gradually increasing abundance of chlorite and epidote in particular. The closing relatively mild phases of hydrothermal action are characterized by the series of zeolites and by carbonates.

The amphibole and the major amount of the iron oxides associated with it are to be regarded as products of pneumatolysis, both on account of their position in the general mineral sequence,

and from the abundance of apatite and occasional inclusions of tourmaline associated with them. The period of magnetite formation may have continued, however, into the early intense phases of the hydrothermal period.

The principal copper ores, chalcopyrite and bornite, commenced to form under pneumatolytic conditions, as indicated by their occurrence in the pegmatite, but they attained their maximum development when accompanied by minerals of accepted hydrothermal origin, and even continued in a feeble way into the period characterized by the zeolites. The percentage of the ores connected with the pegmatites, or as occasional small inclusions in the magnetite, is small, and there seems to be good evidence that the larger part of the sulphides—the part which makes the deposit a commercial orebody—is of hydrothermal origin.

Turner and Rogers regard the ore as a magmatic segregation. From field evidence, Turner considers the sulphides to be the final products of the crystallization of the magma, analogous to the quartz in a granite, and to have been formed before the development of the pegmatites. As a matter of fact, such a view is justified by the general appearance of much of the ore and by many of the broad field relations, though it is contradicted by certain megascopic features, subordinate in distribution but significant in character, such as the schistose structure of some of the ore-bearing rock, and the presence of sulphides both along fractures, and in seams of pegmatite and rarely of zeolites. Rogers concludes, from microscopic examination of Turner's specimens, that the ores are products of gaseous solutions, rich in mineralizers, and evidently assigns to them a later origin than did Turner. Although pointing out that deLaunay groups deposits of such origin under the heading *Gîtes de départ immédiat*, Rogers retains the term "magmatic segregation," because of the close analogy he believes to exist between the ores at Engels and those at Sudbury, Insizwa and other deposits that are commonly regarded as magmatic segregations.

The phase in the geologic history of the Engels deposit which seems to us to correspond most closely to the conditions of origin postulated by deLaunay for the deposits classified by him as

Gîtes de départ immédiat, is what we have termed the pneumatolytic period. The iron oxides at Engels and a small proportion of the bornite and chalcopyrite were formed at this stage. They might possibly be classified as magmatic segregations provided the term may properly be expanded to such an extent. But the close association of the greatest part of the primary copper sulphides with hydrothermal minerals is distinctly different from the conditions as described for Sudbury or other deposits regarded as magmatic, and unquestionably classifies the Engels orebody as a hydrothermal deposit.

Origin of the Chalcocite.

Chalcocite Clearly of Replacement Origin.—Rogers first attributed the formation of chalcocite at Engels entirely to the agency of ascending alkaline waters and considered it a hydrothermal effect. In his later publication he recognizes that chalcocite due to descending waters is present, but maintains that "the evidence in favor of 'upward enrichment' is even stronger than before." The absence of kaolin, the occurrence of chalcocite in massive ore-bearing rocks, and the relation of the chalcocite to the sericite and chlorite are points he has urged to support the thesis of "upward secondary enrichment." They may be considered in order.

The absence of kaolin was advanced in Rogers's first paper as a proof that the chalcocite is not the product of descending solutions. Confirming his observations, we find that kaolin is not a common product at Engels, although small amounts were found in a few cases. The formation of kaolin[8] depends primarily on the presence of sulphuric acid, which in turn is largely derived from pyrite. As no pyrite has been observed at Engels, the lack of kaolin with the oxidized products is not surprising. The solutions descending from the oxidized zone are probably at most only mildly acid, as they do not noticeably attack the carbonate present in the rock or even in the veinlets with which chalcocite is associated, but there is no reason to believe that such solutions

[8] The generalizations in this paragraph regarding kaolin have been drawn in large part from investigations being carried on by our associate, Edward H. Perry.

are incapable of producing chalcocite enrichment. Our observations in many districts indicate that the enrichment of bornite to chalcocite by descending waters is accomplished so readily, and with the production of so little sulphuric acid,[9] that it may take place without the appreciable development of kaolin.

Chalcocite is frequently developed from bornite at Engels in hard, dense rocks beyond the limits of the oxidized materials, but notwithstanding the great ease with which bornite is enriched, this transformation is even here dependent upon the degree to which chlorite and sericite, or microscopic fractures have materially augmented the normal permeability of the ore due chiefly to minute channelways along gangue boundaries.

In his first paper, Rogers assigned an earlier age to the chlorite than to the bornite and chalcopyrite, or the chalcocite, but stated that the sericite is younger than the bornite and chalcopyrite, and that it developed simultaneously and in intimate genetic association with the chalcocite. In his later article, the chalcocite which he attributes to ascending solutions is considered older than both the chlorite and the sericite, while the chalcocite which he ascribes to descending influences is regarded as younger than these gangue minerals. Both kinds of chalcocite, he adds, were formed independent of the process of sericitization, and he now accepts Beeson's explanation of greater permeability to account for the close positional relation observed between the sericite and chlorite and some of the chalcocite.

As we interpret the evidence, the chlorite and sericite laths are to be regarded as inclusions in the bornite-chalcopyrite matrix, yet formed at practically the same time as their host, and perhaps developed with more perfect outline chiefly because of their greater power of crystallization. We find no satisfactory foundation for Rogers's view that the laths of sericite and chlorite have been formed by later replacement of the bornite and chalcopyrite. We are convinced that this is not true for the chlorite. As for the sericite, however, the evidences (pp. 13 and 15) controverting his interpretation are not so abundant or so forceful, and

[9] Zies, E. G., Allen, E. T., and Merwin, H. E., "Some Reactions Involved in Secondary Copper Sulphide Enrichment," ECON. GEOL., Vol. 11, p. 500, 1916.

our dissent from it arises as much from its incompatibility with the tendencies of sequence in sulphide ores in general and from the notable similarity of habit and occurrence between the sericite and the chlorite, as from any compelling evidence against it in this particular case.

With respect to the chalcocite, except for the comparatively small amounts in the graphic areas which will be discussed later, the evidence is conclusive that it is later than the sericite or the chlorite. The greater general development of chalcocite in those parts of the ore containing abundant sericite and chlorite is readily explained as a result of the greater permeability caused by the presence of these micaceous minerals, as already noted.

Between the chalcocite in the lattice structure[10] on the one hand, which Rogers regards as due to ascending alteration, and on the other hand the chalcocite of admittedly descending origin which constitutes more or less regular rims about laths of chlorite and sericite[11] and grains of other gangue minerals[12] or forms veinlets[13] with or without accompanying siderite or limonite, we find it impossible to draw any important distinctions as to genesis, and we are forced to conclude that both kinds of chalcocite were formed in essentially the same manner and by essentially the same means.

Examination of Rogers's Fig. 2, to which reference has been made, and of our Fig. 14 reveals the presence of numerous narrow tongues or spines of chalcocite extending from the chalcocite rims into the bornite cores and arranged in several systems of directions. This feature, which is very common at Engels, we have found in many districts to be simply an early stage of the development of the lattice structure. Moreover, this formation of lattice chalcocite in bornite, the development of narrow gashes or spines of chalcopyrite, with or without chalcocite or covellite (Fig. 15) in bornite near where it is being altered to chalcocite, and the similar production of either felted aggregates

[10] See Fig. 8 of Rogers's article in ECON. GEOL., Vol. 11, p. 582, 1916.
[11] See Fig. 5 of same paper by Rogers.
[12] See Fig. 2 of Rogers's paper and Fig. 14 of this paper.
[13] See Fig. 16 of this paper.

or sharp plates of covellite along bornite-chalcocite boundaries are features very common in connection with the alteration of bornite to chalcocite by the normal process of downward enrichment, as is exhibited in such unquestionable examples as Bisbee, Morenci, Globe, Ajo, Bingham, and Ely. The last two of these features, furthermore, have been produced artificially in the Geophysical Laboratory by the action of solutions containing copper sulphate and sulphuric acid on bornite.

Added to these evidences favoring a descending origin for the chalcocite are several others. The chalcocite, though developed in part by replacement of chalcopyrite, is yielded mainly by bornite; in other words the bornite is much more easily enriched than the chalcopyrite. This is entirely in accord with repeated observations in examples of unquestioned downward enrichment and with the results of experiments in artificial enrichment.[14] In this connection it may be noted that in the conversion of bornite to chalcocite, only a relatively small addition of copper is required to produce a result of important magnitude, for the one mineral contains 63.33 per cent. copper[15] or almost ⅘ as much as the other, viz., 79.86 per cent. Furthermore, the oxidation and leaching of a zone of solid bornite ore would liberate and make available for enrichment at greater depth more than twice as much copper as would a solid chalcopyrite ore of equal thickness. Thus, as regards quantity of chalcocite produced, bornite is doubly at an advantage over any of the sulphides poorer in copper.

In the particular case of the Engels deposit, *all* the chalcocite thus far encountered could have been produced, through enrichment of the original sulphides, by a decidedly smaller amount of copper than has plainly been removed from the upper, oxidized zone, notwithstanding the incompleteness of leaching; and although quantitative data obviously are unavailable, it is not improbable that this source was sufficient, even though the enrichment process may have been wasteful of copper. In any event,

[14] Zies, Allen, and Merwin, *loc. cit.*, pp. 498–499.

[15] Allen, E. T., "The Composition of Natural Bornite," *Am. Jour. Sci.*, Vol. 41, pp. 409–413, 1916.

it is evident that the Engels deposit once continued above the present surface and, as appears later, topographic conditions were favorable for enrichment during the erosion that cut down to the present outcrop. The copper furnished by leaching of a relatively small thickness of the ore now eroded away, added to that removed from the present leached zone, would unquestionably suffice to account both for any reasonable degree of waste in the enrichment process and for an extension of enriching chalcocite in gradually decreasing abundance to a very considerable depth below the horizon to which the mine workings have yet been carried.

As a matter of fact, if *all* the chalcocite at Engels be regarded as due to descending waters, the amount of enrichment is moderate or slight as compared with that in other bornite-rich deposits of comparable physiographic history.

Finally in the upper parts of the mine, there are associated with the chalcocite, veinlets of limonite and of siderite (with perhaps a little quartz), while at greater depth, the limonite disappears but the siderite persists. These products thus disposed are what might be expected to result from iron-bearing solutions at different distances from the source of oxygen supply, *i. e.*, the surface, and of course the fixation of iron in a partly or completely oxidized condition in the circulation channelways at either horizon accords with the idea of replacement of a copper-iron sulphide by a copper sulphide under conditions of descending, oxidizing[16] enrichment. Siderite, associated with a little chalcocite, has recently been described at Bisbee[17] as the deepest product of oxidizing influences. In the Bisbee occurrence, the siderite is largely a replacement of calcite (limestone). At Engels, the siderite in the veinlets is pretty certainly a product of surface influences; but as to the siderite that appears to replace areas of calcite in some of the zeolite-bearing rocks, we are somewhat in doubt whether it likewise was formed by meteoric waters or is

[16] See Spencer, A. C., *Jour. Washington Acad. Sci.*, Vol. 3, pp. 70–75, 1913. Also Graton and Murdoch, *loc. cit.*, p. 65.

[17] Bonillas, Y. S., Tenney, J. B., and Feuchère, Leon, "Geology of the Warren Mining District," *Bull. A. I. M. E.*, Sept., 1916, pp. 1451 and 1457.

a final product of hydrothermal action. Whatever its origin, the total amount of siderite at Engels is insignificant.

Covellite, which at Engels is wholly subordinate in quantity to chalcocite, is a replacement of earlier sulphides, and, like the replacement chalcocite, is competently explained on the ground that it is of superficial origin. We are unable to follow Rogers's argument that chlorite replaces covellite, but find that covellite, like chalcocite, may replace bornite and chalcopyrite along the margins of chlorite laths and along gangue boundaries in general.

In short, we find at Engels that all the clearly *enriching* chalcocite—that plainly formed by replacement of earlier, leaner sulphides—is to be explained as a result of the action of surficial solutions, and that there is no need or justification for resorting to the idea of "ascending secondary enrichment."

Chalcocite in the Graphic Structure.—The discussion under the preceding section applies to the chalcocite which gives ready evidence of having been derived by replacement of bornite (and a little chalcopyrite), and only when *all* the chalcocite of the deposit has been mentioned has reference been intended to the chalcocite that occurs in graphic relation to bornite. This graphic chalcocite is present in amount decidedly subordinate to the chalcocite clearly of replacement origin.

In our opinion, the validity of the hypothesis of ascending origin for part of the Engels chalcocite hinges on the source and character of the chalcocite in the graphic structures. Concerning the origin of the graphic relations between bornite and chalcocite, which have been observed in several districts, a marked diversity of opinion results from the difficulty of the problem and the conflicting nature of much of the evidence.

Various writers[18] have regarded these structures as due to contemporaneous formation of the two components; others[19]

[18] Laney, F. B., *Proc. of U. S. Nat. Museum*, Vol. 40, p. 520; ECON. GEOL., Vol. 6, pp. 399–411. Graton, L. C., and Murdoch, J., *Trans. A. I. M. E.*, Vol. 45, p. 768. Gilbert, C. C., and Pogue, G. E., *Proc. of U. S. Nat. Museum*, Vol. 45, pp. 609–625. Overbeck, R. M., ECON. GEOL., Vol. 11, p. 151.

[19] Rogers, A. F., M. and S. P., Oct. 31, 1914, p. 686; ECON. GEOL., Vol. 8, p. 781; Vol. 9, pp. 359 et seq.; Vol. 11, pp. 582 et seq. Ray, James C. (ECON. GEOL., Vol. 9, pp. 463–481), apparently regards both the bornite and chalcocite

believe that they result from a partial replacement of bornite by chalcocite; and the view has been advanced[20] for graphic structures in general that some may be simultaneous intergrowths and others may originate by replacement.

If the replacement origin of the graphic chalcocite at Engels is to be accepted, as urged by Rogers, we find no reason whatever for differentiating it in any essential respect as to source and age from the chalcocite of clearly replacement origin which we believe is unquestionably due to secondary enrichment of the orthodox kind. But if the graphic chalcocite is a result of descending enrichment, we believe it represents the feeblest effects of that process and is an exceedingly delicate manifestation of bornite replacement. Possible light on this idea is afforded by conditions at the Superior deposit.

The Superior Mine.

An instructive parallel to the occurrence of the ore at the Engels Mine is offered by the neighboring deposit known as the Superior. The hydrothermal character of the ore is very definitely shown in the latter, and the idea that the Engels ore is to a large extent of pneumatolytic and hydrothermal origin, is greatly strengthened by the many points of similarity between the two deposits.

The Superior orebody is situated about two miles to the southwest of the Engels Mine, and approximately 1,200 feet lower in elevation. The ore outcrops on the steep eastern side of a cañon, several hundred feet above the stream near the lower camp at the foot of the aërial tramway from the Engels mill. Aside from the diamond drill holes, the only development on the property in June, 1916, was a shaft about forty feet deep, but a tunnel was being started lower on the slope to intersect the ledge. The orebody consists of veins of massive bornite and magnetite, ranging from thin seams up to a width of six inches or more. They

as replacements of covellite, but considers them to be of simultaneous origin. Later (ECON. GEOL., Vol. 11, pp. 179–185) he states that the graphic structure may originate by the replacement of bornite by chalcocite. Whitehead, W. L., ECON. GEOL., Vol. 11, pp. 1–13.

[20] Graton, L. C., *Trans. A. I. M. E.*, Vol. 52, p. 597.

are spaced a foot or so apart in a fracture zone 10–12 feet wide. The lode as a whole seems to have a high dip, but the individual veins are more or less irregular.

The surrounding rock is a diorite, and is part of the same large plutonic body in which the Engels ore occurs. It is however lighter in color than the rock near the larger mine, and examination shows it to be of more acidic character. The feldspar is andesine with rims of oligoclase or oligoclase-albite, and the hornblende is less prominent than in the darker rock. The veins are accompanied by intense rock alteration. The development of amphibole, chiefly actinolite, at the expense of the feldspar or the original hornblende, is the earliest phase of the mineralization. Apatite in large crystals and titanite in numerous irregular grains are abundant, and were probably produced at this time. Quartz in varying amounts is common under the microscope, but is not prominent in the hand-specimen. It probably commenced to form with the amphibole. The acidic rims of the feldspars may also be products of this early phase of the mineralization. The feldspar, some of the quartz and the amphibole all show the effects of intense stresses. The amphibole, especially, is fractured and sheared. The bornite and its associated minerals are clearly later and take advantage of the channelways thus afforded. The formation of the sulphides was accompanied by the abundant development of small laths of a green mica, and of epidote, chlorite and sericite. The green mica is commonly a replacement of feldspar or of amphibole, and the sericite, the least important from a quantitative standpoint, is largely confined to the feldspar. The latest mineral of the primary sequence is heulandite, which occurs abundantly as a replacement of the plagioclase.

Bornite and magnetite are by far the most abundant ore minerals. The magnetite appears as large grains sometimes boldly euhedral, surrounded by a cement of bornite. The latter also occurs as fine blebs or irregular veinlets in the magnetite; it is clearly of later age and in part a replacement of the iron oxide. The association between the two minerals is more intimate than in the Engels ore, and the magnetite seems to have been more

generally attacked by the bornite than is the case in the larger deposit (Figs. 21 and 22). The absence of specularite and ilmenite is noteworthy. Chalcopyrite is less plentiful than at Engels. A few small blebs of galena were observed.

Chalcocite is present in subordinate amount intimately associated in all cases with the bornite. In small part, it occurs as veinlets and tongues which are clearly replacements. In a few cases, imperfect lattice structures are developed. Chiefly, however, it is in graphic areas or in irregular patches with mutual boundaries, and in these forms, it commonly shows a complete independence of the contacts between the bornite and magnetite (Figs. 21, 22). Where this chalcocite intersects laths of chlorite included in the bornite, the line of contact is in many cases likewise ignored (Fig. 21). In some cases, however, no break can be discerned between chalcocite of the graphic areas and adjacent chalcocite of the replacement type.

Clearly of later age than the more abundant chalcocite just described is a bluish variety of the mineral in tiny veinlets cutting the bornite. Where these cut bornite-chalcocite graphic areas, it is sometimes found that the veinlet appears in the bornite lobes but is not distinguishable in the chalcocite blebs. With the chalcocite in these veinlets, there is a small amount of covellite, malachite, and limonite. A little kaolin and limonite are the only products of surface alteration in the wall rock. The slope upon which the orebody outcrops is very steep, and almost devoid of soil. There is no zone of oxidized material, although faint limonite and malachite stains extend to the bottom of the shaft. The bornite occurs directly at the surface, with only the merest traces of alteration.

The form of the deposit (viz., a definite lode in the diorite) and the nature of the associated minerals (including actinolite, epidote, chlorite, sericite, and heulandite) indicate that the ore is epigenetic, as pointed out by Turner, and of hydrothermal origin. The early formation of amphibole, the dynamic modification of the rock, the subsequent introduction of chlorite, epidote and sericite accompanied by bornite, and the development of heulandite in the closing phases afford, together with the

absence of pyrite, a striking similarity to the sequence and character of the minerals at Engels. The occurrence of the ore in a well-defined lode, the greater abundance of the green mica, the closer relationship between the magnetite and bornite, the slightly greater rock alteration, and the unimportance of products of oxidation and enrichment at Superior are the chief points of difference.

Conclusions as to the nature of most of the chalcocite at Superior rest on the interpretation of the same kind of graphic structures between bornite and chalcocite as are shown at Engels, and the discussion of this subject on pages 32 and 33 applies to both deposits. At Superior, however, it is clear that the chalcocite in these forms is not the product of enrichment from the present surface. The small amount of oxidation under the active mechanical erosion to which the deposit is now subjected may be measured by the feebleness of the veinlets of blue chalcocite and covellite and the slight development of limonite and malachite. Most of the chalcocite is clearly of an earlier age than the veinlets, and, if a product of descending secondary enrichment, it must have been produced under previous topographic conditions. The surface of gentle relief in this immediate neighborhood upon which were deposited the extensive Tertiary gravels of the Jura River[21] appears to have been not far above the present surface at Engels, while perhaps as much as a thousand feet above the Superior outcrop of to-day. There is distinct evidence of at least two later stages in the topographic development, respectively shown by the relatively gentle slopes and open valleys of the higher levels, and the deep V-shaped cañons of the larger streams.

Down at the Superior deposit where the deep incision of the country by an active stream permits only the feeblest present enrichment, most of the chalcocite may be interpreted as the deep roots of an older enrichment formed at a time of less violent degradation. At Engels, where the ore has not yet been reached by the severe erosion of the present cycle, there is a moderately thick cover of oxidized and impoverished material, underlain by a layer of rich chalcocite, and still deeper, by plentiful chalcocite

[21] Diller, J. S., Bull. U. S. G. S., No. 353, Plate II.

that clearly replaces bornite. Although the vertical range of the Engels mine workings is too small to afford conclusive evidence, there is a distinct indication that with depth, the chalcocite of undoubtedly replacement origin decreases in proportion to that in the graphic structures. It may be expected with a fair degree of certainty from the topographic and microscopic evidence that with increasing depth at Engels, the character of the chalcocite will become more and more similar to that observed in the Superior ores. In other words, it is believed that the relations of the chalcocite and bornite exposed in the Superior deposit are similar to the relations between the two minerals in the deeper unexposed portions of the Engels orebody. It is to be noted, however, that this inference is not necessarily dependent upon the interpretation given the graphic structure.

SUMMARY.

The Engels deposit presents an unusually complete record of the varied conditions to which the rock has been subjected from its initial crystallization to the last feeble hydrothermal changes and to the subsequent alterations by surface agencies. The history of the deposit may be summarized as follows:

1. Crystallization of a basic differentiate, of noritic character, from the batholith of the Sierra Nevada. The granodiorite porphyry also probably appeared at this time.

2. Local development of pegmatites; also pneumatolytic alteration of the rock, generally widespread, but occasionally emphasized along seams, producing amphibole, albite, tourmaline, magnetite, and some sulphides, accompanied and perhaps followed by straining, and partial recrystallization.

3 and 4. More localized mineralization and alteration produced under hydrothermal conditions, intense at first, but gradually diminishing, characterized by chlorite, sericite, epidote, and sulphides in the earlier stages, and by zeolites in the closing phases, with increasing dependence upon fractures.

5. Subsequent cracking of the rocks and ores.

6. Exposure of the deposit by erosion to oxidation, with the

production of an impoverished oxidized zone and the development of secondary sulphides.

The first four stages, covering the time from initial magmatic conditions to the close of primary mineralization, are merely convenient divisions of one uninterrupted sequence, while the fifth and sixth were separated from the others, and probably from each other by indefinite time intervals.

In the primary sequence, the presence of mineralizers such as boron and either chlorine or fluorine is indicated at an early stage by the occurrence of tourmaline and apatite, but the chief mineralizer from the beginning to the end was undoubtedly water. Its influence in the early stages is suggested by the presence of amphibole, and the development of the zeolites is conclusive proof of its presence at the close. Much of the rock alteration is probably merely the readjustment of the materials of the rock into forms more stable under the influence of the water vapor or water at high temperatures, without notable additions of new elements, except the iron, copper, titanium and sulphur to form the ore-minerals. The orebody is in our opinion a direct result of igneous action, but was formed as a final concentration following the crystallization of the rock, and not as a direct magmatic segregation.

Secondary enrichment, which followed the exposure of the deposit to oxidizing influences, accounts for all the chalcocite present, with the possible exception of the relatively small amount in the graphic structure, which also we are inclined to attribute to downward enrichment.

These conclusions find support in the conditions exhibited at the nearby Superior deposit and in certain physiographic features of the region.

NOTE ON APPALACHIAN OIL-FIELD BRINES.[1]

G. B. Richardson.

Waters from deep wells in the Appalachian oil fields have long been known to be concentrated solutions of sodium chloride, but comparatively few detailed analyses are on record. A sample from the "hundred-foot" sand, a member of the upper part of the Catskill formation, was collected by the writer in Butler County, Pennsylvania, in 1915 and analyzed in the Geological Survey laboratory. This analysis is here given, together with another Survey analysis of deep-seated water from a well near McDonald, Washington County, Pennsylvania, from a horizon believed to be of Oriskany age by Charles Butts, who is prepar-

Analyses of Water from Deep Wells in Western Pennsylvania.

	Percentage of Dissolved Salts.	
	A.	*B.*
Cl	62.29	61.38
SO_4	.10	.02
HCO_3	None	——
CO_3	None	None
Br, I	——	.26
Na	27.59	24.50
K	.10	1.97
Li	Trace	——
Ca	8.40	9.56
Mg	1.47	.94
Sr	Trace	1.31
Ba	Trace	Trace
Fe"	.05	.06
Fe"'	Trace	——
	100.00	100.00
Salinity, parts per million	131,890	263,640

A. Water from "hundred-foot sand" at depth of 1,359 feet, in well on farm of Charles Hoffman, 5 miles northeast of Butler, Pa. Analysis by W. B. Hicks and R. K. Bailey, U. S. Geological Survey.

B. Water from Oriskany sandstone at depth of "6,300" (6,260?) feet, in well of Peoples Natural Gas Co., 5 miles northwest of McDonald, Pa. Analysis by George Steiger, U. S. Geological Survey. See U. S. Geol. Survey Water-Supply Paper 364, p. 9, 1914.

[1] Published by permission of the Director, U. S. Geological Survey.

ing a report on the record of this well, possibly the deepest ever drilled. The two wells are 40 miles apart, and the water-bearing horizons are separated stratigraphically by about 4,500 feet.

These natural brines are so different from other waters in concentration, composition, and in the relative proportions of the ions present as to belong to a distinct class. Sodium and chlorine constitute 90 and 85 per cent. respectively of the saline matter, calcium is much more abundant than magnesium, carbonate is absent, only small proportions of sulphate are present, and traces of bromine and iodine are characteristic. The salinity of the water from the "hundred-foot" sand (13.19 per cent.) is half that of the water from the Oriskany (26.36 per cent.), which is almost a saturated brine. The salinity of ocean water, it will be recalled, is less than 4 per cent.

The term, connate water, defined by Lane[2] as water "buried with the beds in the first place" has been applied to such waters.[3] But in so far as the term, connate, applied to Appalachian oil-field brines, implies that they are the essentially unchanged waters of the basin in which the beds were laid down the idea is difficult to accept. The high salinity of these brines, the increase of their salinity with depth, and the association of fossil shells, brought up in drilling wells, with some of the strong brines seem to preclude their being "fossil" Devonian water; indeed, in view of the geologic history of the region it seems inevitable that there has been some circulation through the sediments and that the waters must have undergone a series of changes in composition. An active solvent like water cannot remain unchanged in composition so long as it is in contact with soluble material.

The final explanation of the composition of these waters will be preceded by the analysis of many samples collected systematically throughout the region. Meanwhile, as a working hypothesis, it can be considered that the composition of these brines results from prolonged leaching of great masses of sedimentary

[2] Lane, A. C., "Mine Waters and Their Field Assay," *Bull. Geol. of America*, Vol. 19, p. 502, 1908.

[3] See for instance, Johnson, R. H., "The Rôle and Fate of the Connate Water in Oil and Gas Sands," *Trans Am. Inst. Mining Engrs.*, Vol. 51, p. 587, 1916.

beds, partly of marine and partly of subaërial origin, by slowly moving water, and also that salt has been transferred by diffusion. Clarke[4] has pointed out that chloride waters form the end of the series of rock-leaching waters. And Becker observes "that sedimentary rocks do actually carry large quantities of disseminated salt seems to be fairly established by the recent work of the hydrologists."[5] The marked increase of sodium chloride in the Appalachian brines with depth suggests diffusion from beds of rock salt in the Salina formation. Beds of rock salt were found in drilling only 600 feet below the horizon from which the sample of water represented by analysis *B* was obtained and the artesian head in this well forced the water 4,000 feet above the horizon at which it was encountered. The almost total absence of sulphate in these brines may be ascribed to the presence in the water of barium and to the reducing action of organic matter in the rocks. Carbonate cannot exist in strong brines, yet the probable former presence of carbonate waters in the oil-bearing rocks is indicated by calcite in the cement of the sandstones. Thin slides of the "hundred-foot" and other deep-seated rocks brought up by torpedoing show marked cementation, the principal interstitial matter being quartz and calcite. Tests by C. E. Van Orstrand, of the U. S. Geological Survey, show that some samples of the "hundred-foot" sand have porosities as low as 4.5 and 7.3 per cent.

The structure of the rocks in the Appalachian geosyncline doubtless has had important control over the composition of the deep-seated waters. With free circulation of underground water, as in the Dakota artesian basin, saline matter would not tend to accumulate and the water would be fresh. But as the salt-water strata in the Appalachian oil-fields form part of a great syncline, bordered on the west by the Cincinnati anticline and on the east by the sharp folds contiguous to the Allegheny Front, circulation is very slow with practically stagnant conditions in places and thus the ground waters tend to become more strongly saline.

[4] Clarke, F. W., "Data of Geochemistry," U. S. Geol. Survey Bull. 616, p. 177, 1916.

[5] Becker, G. F., "The Age of the Earth," Smithsonian Misc. Coll., vol. 56, no. 6, p. 10, 1910.

THE COST OF COAL.

GEO. OTIS SMITH AND C. E. LESHER.[1]

The price of coal is a matter of vital concern to the average citizen. No less important, however, is the question what our coal actually costs to produce and the interest in this subject is typical of the popular interest in the large productive enterprises of the country. As citizens we recognize the consumer's dependence upon the producer and are taking advanced ground as to their relative rights. In few industries does this dependence seem more vital or the consumer's equity appear larger than in that of producing and selling coal. The per capita annual expenditure for the useful metals is roughly equivalent to that for coal, but few citizens purchase pig iron or bar copper, whereas of the urban population only the dwellers in apartments, boarding houses, and hotels are spared the necessity of buying coal. The consumption of coal in the United States for heating and cooking is between 1 and 1½ tons per capita. A careful estimate for 1915 is 1.1 tons, which happens to be identical with the figure determined for similar consumption in Great Britain in 1898. This nonindustrial consumption is greatest in cities and in the city of Chicago in 1912 it was nearly 2 tons. Of course every citizen indirectly pays for his share of the total consumption which last year amounted to 4.6 tons per capita.

Again it may be that because to a larger degree the cost of metals is charged to capital outlay rather than to the operating expense of life, we appreciate less keenly the unit price of these materials that are not immediately consumed with the using. At any rate, public opinion is more easily brought to a high temperature by considering the price of coal than by considering the price of any other product unless we except gasoline, recent discussion of which has been almost explosive.

[1] Released by United States Geological Survey.

Looking backward as well as forward, one need not be an alarmist to suggest that in the whole field of productive business the coal industry seems the one most likely to be threatened with government operation. The foodstuffs are produced on land owned and operated by the millions, and so far as the production of the raw material for them is concerned, "monopoly" is an unknown word, but when we think of coal, terms like "barons" and "trusts" instinctively come to mind. For these reasons the determination of certain facts connected with coal production and the analysis of the cost elements that enter into the price of coal constitute a timely subject for discussion.

In discussing costs, however, we do not overlook the too evident fact that at times price may far outstrip cost. The price of coal depends upon the balance between necessity for fuel on the one hand and ability to produce and to deliver on the other; the ability to produce is in turn controlled by the labor available and the ability to deliver is dependent upon car supply. Increased foreign demand for American coal, large industrial consumption, unusual weather—all may have great influence on the current price of coal, but none of these is to be considered a factor in the actual cost of production except so far as it causes irregularity in operating expenses and promotes a decrease in efficiency of mine labor. To-day high prices are being received for coal by those who are able to produce and deliver more than their outstanding contracts require. In other words, a few traders may be able and willing to capitalize the urgent necessity of the consumer and their own ability to deliver. The premium for fuel now being paid generally by the consumers of the country and by such traders as have been caught short in their contracts is in reality not properly chargeable to cost of coal but to cost of car and labor shortage, just as in the times of stress accompanying labor troubles the premium paid by their consumers is a part of the price the country pays for strikes.

Four general items of cost must be considered as normally controlling the price of coal to the consumer—resource cost, mining cost, transportation cost, and marketing cost. Under usual conditions each of these items includes a margin of profit which

may seem either excessive or inadequate, according to your point of view. Yet an unbiased consideration of these cost items is absolutely essential as a preliminary to the decision by the public whether we are buying coal at a fair price, and if not why not. As long as it is the popular view that the price of coal is made up of one part each of mining costs and freight costs to two parts each of operators' profits and railroad dividends, with the cost of a certain amount of needless waste on the side, the demand for investigation will continue, and in so far as there is any element of truth in this view, legislative action is justified, even though the prescribed reform may approach the extreme of public ownership and operation of mines and railroads.

As the initial item of cost, the amount charged against the marketed product as the value of the coal in the ground, which for brevity may be termed the resource cost, is perhaps the item most often overlooked by the coal consumer, and for this reason that phase of the subject will be fully considered after the other items are treated. These other items need less discussion in this paper for several reasons: the item of marketing cost is one that can be brought directly under observation by the consumer if he will but study the matter intelligently, the transportation cost can be learned by simple inquiry and its control lies within the province of the Interstate Commerce Commission, and the details of mining cost can best be set forth by the mine operators themselves, for they have now adopted the policy of free discussion of these matters, which they once regarded as sacred from public view. The purpose of this paper, then, is simply to give a summary statement of all these elements in the cost of coal, and some special discussion of the resource cost. In presenting the subject, the senior author assumes responsibility for whatever may be regarded as mere expressions of opinion and the junior author stands behind the statements of fact.

The item of cost first to be considered represents that part of the value given to the ton of coal by the mine operator and the mine worker. This may be termed mining cost, but it must include the operator's selling costs and other overhead expenses as well as the mining costs proper which include the larger ex-

penditures for wages, supplies, and power. This cost plus the resource cost—the royalty or depletion charge—and the profit or loss on the sale make up the value at the mine mouth. The mining cost varies not only between mines of different companies in separated fields but even between adjacent mines of the same company in the same field. Both nature and man contribute to such variation.

It is not practicable to assign a very exact figure to the mining cost—the census of 1909 indicated an average of $1 a ton for bituminous coal and $1.86 for anthracite, but these figures are believed by some operators to be too low. It is possible, however, to show in a general way the distribution of this item; the cost of mining is divided between labor, 70 to 75 per cent.; materials, 16 to 20 per cent.; general expense at mine and office and insurance, 2 to 4 per cent.; taxes, less than 1 per cent. to 3 per cent. for bituminous coal, and 3 to 7 per cent. for anthracite; selling expenses, nothing to 5 per cent., and recently to these items has been added the direct and indirect cost of workman's compensation which may reach 5 per cent. for bituminous coal. The charges for labor, material, and general office expenses are easily understood, as is also a charge for depreciation of plant and machinery; but taxes and selling expenses are important items that may be overlooked by the casual observer. Some figures recently published show that the taxes levied in West Virginia last year on coal lands and coal-mine improvements—that is, on the industry as a whole—were equivalent to nearly 3 cents per net ton of coal produced, which is doubtless fully as much as the profit made by many of the operators in that State.

The cost of selling coal is nothing for the companies that use their own product, including the Steel Corporation and a large number of others, and is little or nothing for the producers who sell nearly all their coal to such large consumers as the railroads. Companies that produce coal for domestic use and the general run of steam trade must figure on a selling cost as high as 10 cents or more per ton, the cost depending on the extent of their business. The average selling cost for bituminous coal is prob-

ably 5 to 10 cents a ton, and for anthracite the usual charge of sales agencies is reported as 10 cents a ton for steam sizes and 15 cents for the prepared sizes.

The producers of coal and the transportation companies are concerned not so much with the actual rates charged for carrying coal as with the adjustment of rates between different coal fields and between different markets. In the many years in which our coal industry has been developing, rate structures have been built up that give to this and that producing district differentials over other districts—"handicaps," as it were—that may be based on comparative lengths of haul or on the ability of the coals to compete by reason of difference in quality or in cost of mining or perhaps may be merely the survival of past practice, for which no reason now exists. The consumer of coal, however, is interested in the actual rather than the relative freight rate.

To help toward a realization of the magnitude of this transportation item, it may be pointed out, first, that all but 14 per cent. of the output of the country's coal mines, aggregating 532 million tons, is moved to market by rail or water, and second, that nearly half of the bituminous coal (47 per cent. in 1915) and more than two thirds of the anthracite (71 per cent. in 1915) is shipped outside of the states in which it is produced.

Add to this statement of the extent to which coal enters interstate commerce a glance at the distribution of centers of maximum production and maximum consumption—the New York-Baltimore industrial zone, which has a total per capita consumption of nearly 10 tons and lies 100 to 400 miles from the tributary coal fields; New England, consuming about 7 tons to the unit of population and lying 400 to 800 miles from its coal supply; or the populous industrial district of which Chicago is the commercial center, consuming 8 to 9 tons per capita of coal in part hauled more than 400 miles from the fields of West Virginia and eastern Kentucky and in part 200 miles or less from the Illinois mines. With these facts in mind we must realize that the transportation cost is necessarily a large part of the country's fuel bill.

As has already been suggested, the transportation rate in force

from any coal field to any market can readily be learned by the consumer who wishes to figure this item in the cost of the coal he buys. Therefore in the present general consideration of the subject it is sufficient to state the average value of this item. In the interstate traffic, both rail and water, bituminous coal probably pays an average freight of nearly $2 per ton. In other words, the transportation costs more than the product and, as some parts of the country are just now learning, is sometimes more difficult to obtain. The value of coal like the value of so many other commodities is a place value.

The average freight charge on anthracite is higher than that on bituminous coal, first because the rates are higher and second because according to the reports of the Interstate Commerce Commission, *all* movement considered, the coal is carried as greater distance.

The cost of handling the coal, exclusive of freight, from the time it leaves the producer until it is in the consumer's fuel bin, may be termed the marketing cost. It can readily be seen that a large part of the coal produced is not subject to this cost for most large users of steam coal, such as the railroads and the coke manufacturers, place contracts directly with the producing companies or their selling agencies and buy in the open market only when their needs exceed the deliveries under their contracts. Much of the coal, however, both anthracite and bituminous, passes through the hands of a wholesale dealer or jobber before it is received by the retail dealer who puts it in our cellars or in the bins of a power plant. Coal that gets a long way from the mine may pass through many hands before it reaches the consumer, and it not only pays commissions all along the line but is subject to shrinkage and deterioration, both of which enter into the final selling price to the consumer. Brokers are usually satisfied to make a gross profit of perhaps 10 cents a ton, but as several brokers may make a "turn over" on the same car before it is unloaded this element of cost may be several times that amount.

About half of the anthracite and around 15 per cent. of the bituminous coal is retailed in less than carload lots, and the greatest number of individuals are directly concerned in the

marketing of this portion, regarding the profits on which there is the widest divergence of opinion. The margin in the retail business between cost on cars and price delivered is between $1.25 and $2 a ton and is not more than enough to give on the average a fair profit. The shrinkage and, in part, the deterioration are together seldom less than 1 per cent. of the weight and may exceed 4 per cent., and the retail dealer also must provide in his selling price for uncollectible accounts.

Advertising is a large expense—in part carried by the retailer directly, but all borne by the industry. The largest single item in the cost of retailing is of course that representing the labor of handling and the local cartage, which together make up about half the marketing cost.

There now remains to be considered the first major item, or the resource cost, which is what the operator has to pay for the coal in the ground—the idle resource, which he starts on its career of usefulness. This cost is expressed as a royalty or a depletion charge.

One of the latest leases by a large coal-land owner provides for the payment of 27 per cent. of the selling price of the coal at the breaker. This percentage is therefore not only a royalty figured on the mineral resource but also a commission based on the miner's wage. To bring this right home to you and to me, it may be said that the practical result is that if the anthracite we burn in our range this winter happens to come from that particular property, we will pay fully $1 a ton into the treasury of the city trust that owes its existence to the far-seeing business sense of a hard-headed citizen of Philadelphia. Whether such a royalty is excessive or not the fact remains that this is the tribute paid to private ownership.

The present average rate of royalty on anthracite is probably between 32 and 35 cents a ton on all sizes, which is from 12 to 14 per cent. of the selling value at the mine. The minimum rate (about 10 per cent.) is found in some old leases, and the maximum (20 to 27 per cent.) in leases made in the last five years. R. V. Norris states that in the late sixties, when the annual output of anthracite was around 15,000,000 tons, royalties were 8 to 10

cents a ton on prepared sizes, but that no charge was made on the smaller sizes. In the seventies the rate rose to 25 cents on prepared, one half that on pea, and one fourth on smaller sizes. By the middle eighties, when the output was a third what it is now, the rate was about double that of the seventies—that is, 40 to 50 cents on the larger sizes and 5 to 10 cents on the smaller sizes. The tendency is still upward by reason of increases in the rates for intermediate sizes and the operation of royalty rates based on a percentage of the selling value, an increasing quantity. Figured on the output from the Girard lands, which is nearly 3 per cent. of the total production, the gross return to the estate from its coal lands is over 50 cents a ton.

Nor is the increase in value of anthracite lands any less striking. At the beginning of the last century, as stated by Mr. Norris, the great bulk of these lands were patented by the state of Pennsylvania for $2 to $4 an acre; in the middle of the century the price of the best land rose to $50, and in 1875 even to $500. Now $3,000 an acre has been paid for virgin coal land, and little is on the market at that. In considering these increases in land values, the effect of interest and taxes must not be overlooked.

The bituminous coal industry is a modern institution compared with the mining of anthracite, and much of the bituminous coal land was acquired by the operating companies during the last twenty years for little if anything more than its surface value. To-day there are large areas of bituminous coal-bearing lands that, because they are undeveloped and without railroads, can be purchased at a low price, but little or no anthracite land is on the market, and little has changed hands for years. The present average resource cost of bituminous coal is not much over 5 cents a ton, or about 4 per cent. of the average selling value at the mine. In the Pocahontas region and the Pittsburgh district the royalties are much higher, but these like others that might be cited, are exceptions—one due to coal of special quality, and the other to location—factors which, incidentally, are exactly those that have assisted in making the resource cost of anthracite what it is.

Should you be interested in summing up all these various costs and striking a balance between labor's share and capital's return, you would find that the mine worker, the trainman, and the wagon driver together receive fully half of the price of the anthracite delivered at your house, and the same three classes of labor receive not less than half the price paid by the average consumer for the cheaper soft coal. In a similar manner the average return on the capital invested in land, mining plant, railroads, and coal yard may be roughly calculated, with the result that landlord, bondholder and stockholder of coal company and railroad together receive about $1.15 from the ton of anthracite and only 50 to 75 cents from the ton of bituminous coal, and of either of these amounts the mine operator's share is only a small fraction.

It is not the purpose of this analysis of costs to offer any cure-all for the high price of coal, yet some comment on the facts presented may possess value. At least certain lines of approach can be pointed out as not very promising. For example, anyone who is at all cognizant of the trend in price of labor and material can see little hope of relief in lower costs for these items. Furthermore, observation of the advances made in mining methods in the last decade or two affords slight warrant for belief in any charge of wasteful operation. As consumers of coal we might do well to imitate the economy now enforced by the producers in their engineering practice. In the Northern Anthracite field machine mining is extracting coal from 22 and 24 inch beds, and throughout the anthracite region the average recovery of coal in mining is 65 per cent., as against 40 per cent. only twenty years ago. Nor are the bituminous operators any less progressive in their conservation of the coal they mine.

Yet it must be remembered that conservation of a natural resource, though it will undoubtedly be of direct economic benefit in the future, is not essentially a cheapening process; in fact, these increased recoveries of coal have in large part become possible only because of a higher market price. And, following further this line of thought, we may say that the increased safety in the coal mines that has come through the combined efforts of

the coal companies, the state inspectors, and the Federal Bureau of Mines necessarily involves some increase in cost of operation, but the few cents per ton thus added to the cost is a small price to pay for the satisfaction of having the stain of blood removed from the coal we buy. That form of social insurance which is now enforced through the workman's compensation laws alone adds from 2 to 5 cents a ton to the cost of coal.

In the item of transportation perhaps the most promising means of relief is that of reducing the length of haul. Though many a consumer's preference for coal from a distant field over that from a field nearer home is based on special requirements, the deciding element in the preference of other consumers is simply the price, and this in turn may be largely due to a differential freight scale, which is thus not in the public interest if we admit the premise that it is wasteful to burn coal in hauling coal into coal districts or past such districts, except in so far as quality requirements absolutely demand the long-haul coal. The recent eastward movement of the higher-grade coals, in part caused by the export demand, may involve some increase in the average length of haul and thus in the transportation cost of coal not exported, but on the other hand this enforced adjustment may lead some consumers to discover nearer home sources of coal equally well suited to their purposes.

Reduction in marketing costs is a reform so close to the consumer that he should be able to find for himself whatever relief is possible. Professor Mead, of the University of Pennsylvania, is authority for the statement that the delivery of coal is costing the dealers 50 cents a ton more than is necessary.

There only remains, therefore, the first item of all—the value of the coal in the ground, or rather the return which the landowner is asking for this natural resource. The fortunate holder of coal land, whether a very human individual or a soulless corporation or a large trust estate administered for benevolence only, is likely to endeavor to get all that the traffic will bear. Especially in the possession of a limited resource like anthracite, the tendency has been and will continue to be to increase royalties as the years pass, and the only penalty imposed by the state for

high royalties seems to be high taxes, which too often, indeed, serve to justify the high resource cost put upon coal in the ground. Finally, in considering royalty rates or depletion charge we must not overlook the interest that accumulates throughout the period between the purchase of the coal land and the removal of the last ton of coal.

In placing a value upon the Choctaw lands some years ago the Geological Survey figured the aggregate royalties at current rates as 160 million dollars, but if that amount of royalty were to be collected through the six or seven centuries required for mining the two thousand million tons under this land, the present value of the land would be only 6½ million dollars if purchased by the federal government or only 4 million if purchased by the state of Oklahoma, and even less if the project were financed by a corporation that would need to issue 6 per cent. bonds. Such is an illustration from actual experience in coal-land valuation—the 4 or 6 million dollars invested in these Oklahoma coal lands now would require a final return of 160 million dollars in royalties to balance the account.

More recently Mr. Cushing, the editor of *Black Diamond,* has figured the cost of a monopolistic control of the available coal resources east of the Rocky Mountains on the basis of the United States Geological Survey estimate of two million million tons. At a valuation of coal in the ground of only 1 cent a ton, which as he stated is less than has been paid for large holdings, this deal would require a capitalization of 20 billion dollars, and the fixed charges on the bonds of this United States Coal Corporation would require an interest charge alone of $2 a ton against a production of 600 million tons a year. Mr. Cushing characterizes such a financial undertaking in mild terms as hopelessly impossible, and yet his figures, which do not include taxes, are most enlightening as affording some measure of the cost of possessing an undeveloped resource. Incidentally, these startling figures furnish a strong argument for the present policy of the National Government in retaining ownership of the public coal lands, at least up to the time when the market conditions justify the opening of a mine and then either leasing or selling a tract

only large enough for that operation. The consumer of the next century simply can not afford to have private capitalists invest to-day in coal land for their great grandchildren to lease.

The burden that seems evitable under unregulated private ownership of a natural resource like coal is that because the lands containing these national reserves of heat and power are taxed and because the individual or corporation properly charges up interest at current rates on his large holding, the consumer must pay a resource cost which takes into account the long period of undevelopment. Even the high rates of royalty on the lands of the Girard estate may be found less excessive than they seem if a century's taxes and interest charges are figured. Yet the fact remains that the royalty for anthracite represents a much larger proportion of the cost of the mined coal than any bituminous royalties. Moreover, we believe the highest royalty prevailing in the anthracite region has far more influence in fixing the selling price than the lower rates of the older leases.

Any study of costs in the coal industry finds its point in the question not who but what fixes the price of coal. The cost of mining coal, like the cost of living, is increasing. Exact mining costs, however, can not be determined until the operators have accomplished their reform of standardizing accounting. Too often the operator includes in his account only the two largest and most obvious items, labor and material. Thus, when the market for bituminous coal is dull, the company whose land costs little or nothing is able to set a lower limit of price than the company whose coal must stand a charge of 5 to 10 cents per ton or even more, be that charge called royalty, depletion, or amortization. At such times the operator with the larger resource cost must sell at a real though not always recognized loss, but of course with the hope of recouping himself at times of high prices like the present, if fortunately he has any coal to sell not already contracted for.

Even with the average low resource cost of bituminous coal, the state of competition that is tied up with idle and half-worked mines results in an average total cost that is little below the average selling price. Of course in this business there are those,

both large operators and small, who make a profit in lean as well as in fat years, just as there are those for whom the prosperous years are too infrequent to keep them out of the hands of receivers.

In the anthracite fields the mining costs and especially the resource costs are higher. But here, with an average market demand that normally exceeds or at least equals the available supply (and with the passing years this disparity must be expected to increase), there results naturally a lack of competition for the market. Even gentlemen's agreements are unnecessary as long as every operator can reasonably expect to sell his product, and the market price of anthracite at the mine must therefore tend to be fixed by the operator who has the largest mining and resource cost rather than by his neighbor who may be doubly favored with a mine less expensive to work and a lease less exacting in terms.

Confessedly, this analysis of the cost elements that enter into the price of coal emphasizes our lack of specific facts, which can be supplied in the future only through "installation of uniform cost-keeping methods and uniform and improved accounting systems" to quote from the declaration of purposes of the Pittsburgh coal producers. With the results of such bookkeeping in hand, more definite reply can be made to the public's appeal for relief from high prices. Yet even now it may be possible to suggest how that relief will eventually be obtained. Study of present conditions in the coal mining districts fails to encourage the idea of governmental operation of the seven thousand coal mines in this country. More in line with the trend of public sentiment in the last decade, however, is governmental control in the interest of the consumer by regulation of prices, and to judge from the facts of experience in the regulation of transportation of other public utililties, the public coal commissions will be given sufficient discretionary powers to safeguard the interests of producer and consumer alike, and even mandatory requirements, either legislative or executive, will be subject to judicial review.

Competition seems to have failed of late years to benefit the consumer of coal. In the bituminous fields the competition when-

ever present has been wasteful and in the anthracite fields there has been practical absence of healthy competition and whether too great or too little competition, the result is the same—to increase the actual cost of bituminous coal by saddling the industry and its product with the fixed charges on idle or semi-idle mines and to raise the price of anthracite coal by favoring the burdens of high resource costs.

In estimating the aggregate losses incurred by society by reason of the large number of mines not working at full capacity, the facts to be considered are that the capital invested in mine equipment asks a wage based on a year of 365 days of twenty-four hours, while labor's year averaged last year only 230 days in the anthracite mines and only 203 days in the bituminous mines with only five to eight hours to the day.

As coal is more an interstate than intrastate commodity, any regulation of prices needs to be under federal control, and to benefit both consumer and producer such control can not stop with transportation and mining costs but must stand ready to exercise full rights as a trustee of the people over the coal in the ground. The private owner of coal land, which derives its real value from society's needs, has no more sacred right to decide whether or not that coal shall be mined when it is needed by society or to fix an exorbitant price on this indispensable national resource than the coal operators have to combine for the purpose of exacting an excessive profit from the consumer, or the railroads to charge all that the traffic may bear. The proposal to bring landowner under the same rule as mine operator and coal carrier may seem radical, but where is the point at which coal becomes the resource upon which industrial society depends for its very life?

Public regulation, however, will be fair and indeed in the long run will prove beneficial to the landowner as well as to the consumer, to the mine worker as well as to the operator, because any such agency as the Federal Trade Commission, in its control of prices, must determine costs; and as we interpret the present attitude of the whole coal-mining industry the operators are willing to rest their case on a fair determination of actual costs on which their profits may then be figured.

THE INTERPRETATION OF WATER ANALYSES BY THE GEOLOGIST.[1]

G. SHERBURNE ROGERS.

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INTRODUCTION.

Geologists have long recognized that waters are more or less powerful agents in the chemical alteration of rocks and ores, and in recent years considerable study has been given to the geologic processes in which underground waters participate. In the laboratory the action of simple solutions on rocks and minerals may be minutely studied and clearly defined, but the nature and the degree of the activity of complex natural solutions is more difficult to estimate. There is no lack of information as to the composition of underground solutions; the difficulty lies in the practical application of these data to geologic problems, or in the interpretation of the analysis from the geologic standpoint. The analysis *per se* is simply an inventory of the substances present in the water, but if properly interpreted it becomes a basis for classi-

[1] Published by permission of the Director of the United States Geological Survey.

fying the water or comparing it chemically with water from some other horizon or locality; it becomes an index of the history and geologic associations of the water, and may afford a measure of its potency as a geologic agent. Unless the analysis is to be simply an inventory some form of statement other than that commonly submitted by the analyst is desirable; and the problem of devising a form of statement which will show in a simple manner the composition of the water and at the same time its chemical quality has puzzled water chemists for many years.

A valuable contribution to the geochemical interpretation of water analyses was made in 1911 by Chase Palmer.[2] In his original article Dr. Palmer discusses chiefly the application of his system to surface waters, but his scheme has since been used by several chemists and geologists in the study of groundwaters of various types. From experience with this scheme the writer is convinced of its practical value, and believes it advisable to bring it again to the attention of geologists. The present paper reviews this system as tested and extended in the course of several years' use, examines the chemical principles on which it is based, and on the basis of a few actual examples drawn mostly from recent literature, discusses its value to the geologist. Much of the material contained herein is the outcome of discussion with the writer's colleagues on the United States Geological Survey, to whom his grateful acknowledgments are due.

In analyzing a natural water the chemist determines only the quantities of the various inorganic substances dissolved in a given quantity of the water. He can not determine what compounds have been dissolved nor can he ascertain by the ordinary methods of analysis what compounds, if any, exist in the solution; his work is for the most part limited to the determination of the portions of compounds that are known as roots or radicles. A list of the weight of each determinable radicle present in a given quantity of the water constitutes a report of the analysis of that water and contains the facts upon which any form of interpre-

[2] Palmer, Chase, "The Geochemical Interpretation of Water Analyses," U. S. Geol. Survey Bull. 479, 1911.

tation must rest. Hence, no matter what form of statement is used as a basis for interpretation, the report of an analysis should always include this list of the roots of substances actually determined by the analyst, which is commonly known as the ionic form of statement. In general, this may best be expressed in parts per million of the water, though occasionally larger units may be more convenient.

The mere statement of the weights of the constituents present is not, however, a numerical representation of the chemical quality of the water, and it may be misleading to one not thoroughly familiar with the relative capacity for reaction of the several constituents. It is not in itself a chemical expression, but is purely a statement of physical results. The physical weight of a radicle does not express its chemical value in a system of dissolved salts such as exists in a water, and the fundamental chemical qualities of the solution are not apparent in an analysis stated in this way.[3]

"Chemical literature furnishes abundant evidence that the statement of water analyses in a form which does not recognize the *proportional reaction capacity* of the radicles fails to show the chemical character of the waters. Waters differing widely in character may be grouped together as similar if the classification is based on the preponderance of any radicle that may be considered as dominant in a solution of salts, or on the apparent predominance of two or more radicles selected merely because they contribute largely to the weight of the mixture. Such classifications may be interesting from several points of view, but they are unreliable guides to the solution of geologic problems involving chemical processes."[4]

The system of interpretation and classification proposed by Palmer is based on the principle that natural waters are balanced chemical systems having definite measurable properties. These properties by no means replace the complete analysis as a basis for study, but they summarize the composition of the water in a convenient "character formula," suggest the geologic associations of the water, and constitute an approximate measure of its potency as a geologic agent.

[3] See Wanklyn, J. A., "Water Analysis," p. 115 (1896).
[4] Palmer, *op. cit.*, p. 7.

Although Palmer's system is based directly on the properties of the water, the properties themselves result from the proportional chemical value of the dissolved mineral constituents. All solutions may be regarded as homogeneous bodies through which the mineral substances are uniformly distributed; hence "the properties of liquid solutions are continuous functions of their composition, calculated in terms of the pure substances of which they are composed."[5] In other words, the properties of a solution are an assemblage of the properties of all its constituents, and therefore the properties of a water may be deduced from the analytical statement. If desired, however, these properties may be quantitatively determined directly in the solution, by the methods of volumetric analysis, without determining the proportions of the radicles present. All but one of the properties entering into the character formula devised by Palmer may be determined directly according to the methods of Hehner,[6] and in fact it has long been customary to estimate them by less exact methods and to use them under the names permanent and temporary hardness, alkalinity, etc., in classifying waters commercially. Blacher,[7] of the Riga Polytechnicum, has recently devised more refined methods of determining the properties, and on this basis has proposed a system of statement and interpretation somewhat similar to Palmer's.

The interpretation of an analysis according to the system here discussed therefore involves two steps:

A. The calculation, from the analytical statement, of the proportional chemical values of the several constituents, according to the law of reciprocal proportions.

B. The summation of the chemical equilibria thus made apparent, in terms of measurable properties.

The form of statement resulting from the first step furnishes a rational chemical characterization of the water and affords a

[5] Ostwald, W., "The Fundamental Principles of Chemistry," p. 97, 1909.

[6] Described by Sutton, "Volumetric Analysis," 9th ed., p. 70.

[7] Blacher, von C., Koerber, A., and Jacoby, J., "Die systematische Schnellanalyse der Gebrauchswasser," *Zeits. für angewandte Chemie*, Band 22, p. 967, 1909.

basis for detailed study. The character formula deduced from this detailed statement sums up the composition of the water, and shows at a glance that portion of the chemical system which is relatively inert and unavailable and that which is relatively free and available, thus indicating the probable nature of the chemical action of the water under many conditions.

USE OF REACTING VALUES.

The first step necessary in the interpretation of an analysis is the translation of the physical weights of the constituents into a form which will express their chemical value in the solution, or their reaction capacity. Stabler[8] has suggested that this be done by multiplying the weight of each radicle by its "reaction coefficient," which he defines as the chemical racting power of a unit weight of the radicle. The reaction coefficient of a radicle is the ratio of the reaction capacity of one part of that radicle to the reaction capacity of eight parts of oxygen; or the valence of the radicle divided by its atomic weight. When these factors are multiplied by the physical weights of the corresponding radicles, chemically comparable figures result which express the reacting values of the radicles. Suppose, for example, that an analysis shows 10 parts of magnesium and 39.5 parts of sulphate. The reaction coefficient of magnesium is .0822 and that of sulphate is .0208 (see p. 19). When these factors are applied, respectively, to the weights of these two radicles it is found that the reacting value of the magnesium present in this solution is .822 and that of sulphate is also .822. Thus when the very different chemical capacity of the two radicles is taken into account it is found that exactly equivalent amounts are present, a condition which the statement by weight does not disclose. The letter *r* may be prefixed to the symbol of a radicle to distinguish the figure expressing its reacting value from that expressing its weight.

[8] Stabler, Herman, "The Industrial Application of Water Analyses," *Engineering News*, Vol. 60, p. 355, 1908; also U. S. Geol. Survey Water Supply Paper 274, p. 165, 1911.

Since reacting values take into account not only the chemical capacity but also the actual quantity of the radicles present they vary with the concentration of the solution. Thus, if the solution referred to above were diluted with an equal volume of pure water the reacting values of the magnesium and sulphate would be .411 instead of .822. Since natural waters vary greatly in concentration the direct reacting values are not entirely satisfactory for purposes of comparison. Palmer has suggested eliminating the factor of concentration by rating the total reacting value of all the radicles as a hundred and proportioning the value of each radicle to this total; in other words, by expressing the reacting values in per cent. The concentration of the solution must be given due consideration in any study of natural waters, but since it governs the rate rather than the nature of the action of the water it is generally not of prime importance from the geologic standpoint.

CLASSIFICATION OF WATERS.

The statement of a water analysis in terms of the ratios, by reacting values, of each radicle to the sum of all the radicles, is a detailed, rational, chemical characterization of the water solution. Like the statement in ionic form, it is purely a statement of fact and involves no assumptions or hypotheses, but it differs materially from the ionic form of statement in that it discloses the chemical nature of the solution. It is not merely an inventory, but is a valuation. As a basis for general comparison, however, it is cumbersome because of the many items that must be taken into account and the variations of each. This feature is overcome by separating the radicles according to their chemical nature into a few groups and basing preliminary comparison and classification upon the proportional values of these groups. The commoner radicles fall readily into well-defined classes established by long chemical usage. Sodium and potassium, for example, may be grouped together because they occur together in nature, are mutually interchangeable in minerals and in natural

solutions, and have the same valence; most of their salts are highly soluble, have a similar effect in many industrial processes, etc. Calcium and magnesium are grouped together because of their natural geologic association and chemical interchangeability, their like valence, the small solubility of many of their salts, and the fact that they cause the property known as hardness in waters. In some processes calcium and magnesium have very different effects and must be considered separately, but from a geochemical standpoint they are closely related. Hydrogen and the metals, or weak bases, form a third natural class, though in special studies it may be found desirable to subdivide this class also. The acid radicles fall naturally into two groups which are designated strong acid (*e. g.*, Cl, SO_4) and weak acid (*e. g.*, CO_3, S) respectively.

According to the relative values of the several groups of constituents all natural waters fall into one of the following classes:

Class 1. Value of strong acids less than value of alkalies.
Class 2. Value of strong acids equal to value of alkalies.
Class 3. Value of strong acids greater than value of alkalies but less than alkalies plus earths.
Class 4. Value of strong acids equal to value of alkalies plus earths.
Class 5. Value of strong acids exceeds alkalies plus earths.

Classes 2 and 4, which represent merely the lines of division between the three main classes, are included chiefly for the sake of philosophical completeness. It is evident that this classification by balance, which originated with Palmer, is based upon simple and consistent definition and that it involves no assumptions other than those made in the preliminary grouping of the radicles themselves. Its value depends on the fact that a solution in which strong acids are exactly balanced with strong bases is relatively inert, whereas one in which either group exceeds the other is relatively active.

DERIVATION OF THE PROPERTIES.

The balance between the several groups of constituents may again be used to subdivide the main classes. This is done by deducing certain specific properties, to which special names are given. The alkalies or strong bases are designated primary constituents, the alkaline earths are called secondary, and hydrogen and the metals, the weak bases, form the tertiary group. Salinity is the property in which the strong acid radicles participate, for these radicles yield saline salts. The weak acids of course also form salts, but in solution their salts hydrolyze and form bases (hydroxides) whose energy greatly exceeds that of the weak acids. In other words, weak acids are incapable of overcoming the natural tendency of strong bases to form alkaline solutions, and therefore solutions of weak acid salts are alkaline. Combining these terms, the strong acids in connection with the alkalies, or primary bases, may be said to induce the property of primary salinity; in connection with the alkaline earths, secondary salinity, and in connection with hydrogen or the metals, tertiary salinity or acidity. The terms primary, secondary, and tertiary alkalinity are similarly derived, as indicated in the following diagram:

	Acids	
Bases.	Strong Acids (*e. g.* Cl, SO_4).	Weak Acids (*e. g.* CO_3, HCO_3).
Alkalies (*e. g.*, Na, K).....	Primary salinity	Primary alkalinity
Alkaline earths (*e. g.*, Ca. Mg)..	Secondary salinity	Secondary alkalinity
Metals (*e. g.*, H, Fe).....	Tertiary salinity	Tertiary alkalinity

It may be noted that secondary salinity is synonymous with permanent hardness, and that secondary alkalinity is the property commonly known as temporary hardness. Primary alkalinity has been called permanent negative hardness, though the important distinction between primary and secondary alkalinity has not generally been recognized.

The manner in which the properties are quantitatively deduced from the analysis is based upon the fundamental rule that strong acids or bases under ordinary conditions displace weak acids or

bases.[9] In accordance with this principle the strong acids are balanced first against the strong bases or alkalies; any excess remaining over the value of the alkalies is balanced against the alkaline earths, and any excess then remaining against the weakest bases, the metals. After the strong acids have been balanced the weak acids are balanced against the basic radicles in the same order.

The manner in which the properties are quantitatively deduced is shown in the figure. Suppose, as in case 3, that the analysis shows (by reacting values) 25 per cent. of alkalies, 20 per cent. of earths, and 5 per cent. of metals, and 30 per cent. of strong acids and 20 per cent. of weak acids. Since the value of primary salinity is the sum of equal values of the alkalies and strong acids, it is limited by the smaller of its two components. In other words, the 25 per cent. of alkalies present and an equal value of strong acids together form 50 per cent. of primary salinity. This leaves 5 per cent. of strong acids to balance with an equal amount of earths and form 10 per cent. secondary salinity. Of the 20 per cent. of earths present 15 per cent. is thus left to balance an equal amount of weak acids and induce 30 per cent. of secondary alkalinity. This leaves the 5 per cent. of metals, which with the remaining 5 per cent. of weak acids, form 10 per cent. of tertiary alkalinity. The water is therefore characterized by 50 per cent. primary salinity, 10 per cent. secondary salinity, 30 per cent. secondary alkalinity, and 10 per cent. tertiary alkalinity. These values sum up the character of the water in a formula, which affords a basis for classifying the water or comparing it with any other water.

Although the six properties named are all found in waters,

[9] According to the principles of physical chemistry the strength of a base or acid depends on the degree to which it is ionized in solution. The statement that strong acids displace weak acids is not intended to imply the idea of chemical affinity. "The real engendering cause of the reaction is not what has hitherto been supposed, *i. e.*, it does not lie in the 'attraction' of the stronger acid for the metal, but in the tendency of the ions of the weak acid to pass into the non-ionized condition." (Ostwald, "Foundations of Analytical Chemistry," p. 64, 1900.)

some of them are incompatible and no one water can be characterized by more than four. Two of these are common to nearly all waters. Thus, if any strong acids and any alkalies are present primary salinity will be a property of the water, and if any weak acids and any metals are present tertiary alkalinity will be

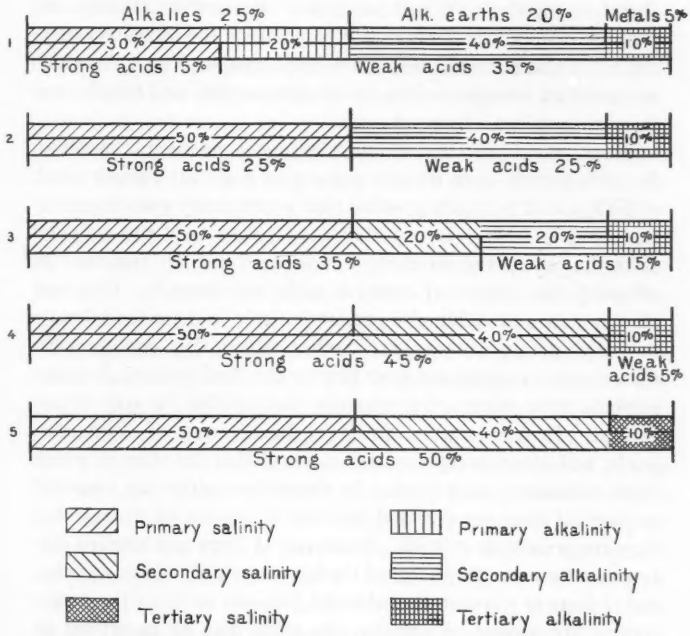

FIG. 1. Diagram showing the five classes into which waters may be divided and the manner in which the properties of a water may be deduced from its analysis.

a property. These properties are generally not distinguishing characteristics and are therefore unsuitable as a basis for classification. The remaining properties, however, are found only in certain types of waters, and the distribution of these properties harmonizes with the primary classification of all waters into five

groups. Thus, if the strong acids are less than the alkalies primary alkalinity is present, but if they are greater secondary salinity is formed; if the strong acids are less than the alkalies plus the earths secondary, alkalinity is present, but if they are greater tertiary salinity will be formed. Primary alkalinity is therefore incompatible with secondary and tertiary salinity, and tertiary salinity is incompatible with primary and secondary alkalinity. These relations are shown graphically in FIG. 1, in which are assumed constant values of alkalies, earths, and metals, and increasing values of strong acids.

Silica, iron oxide, and alumina have not yet been considered. In some waters silica may be present as a silicate radicle (such as SiO_3), and it is quite possible that it commonly goes into solution in this form. It probably soon passes into the colloidal state, however, and in most waters need not be regarded as affecting the system of reactive acids and bases.[10] Iron and aluminum are probably also present entirely in the colloidal state in many surface waters, but in other waters they doubtless become reactive radicles and enter into the chemical system. In many sulphate mine waters, for example, the radicles Fe and Al are present. In most waters, however, the amounts of silica, iron oxide, and alumina reported are so small that the state in which these substances exist cannot be determined either by chemical or physical measurement, and it is best to assume arbitrarily that they are present as colloids. However, if there is a marked discrepancy between the values of the known acid and basic radicles, and if there is warrant for believing that one or all of these substances are present as radicles, the silica may be calculated as silicate and grouped with the weak acids, and the iron and aluminum may be grouped with the metals.

BALANCING THE ANALYSIS.

Chemists have long used reacting values under the term "milligram equivalents" in order to ascertain the accuracy of a water

[10] F. Kohlrausch, *Zeitsch. physikal. Chemie*, Vol. 12, p. 773, 1893. L. Kahlenberg and A. T. Lincoln, *Jour. Phys. Chem.*, Vol. 2, p. 77, 1898. R. B. Dole, *Jour. Ind. and Eng. Chem.*, Vol. 6, p. 712, 1914.

analysis. The acid and basic radicles in any chemical system must have the same value, and any discrepancy may be set down to analytical errors. Stabler[11] has proposed that the percentage of error due to inaccurate analysis, undetermined radicles, etc., be found from the formula $e = 100(rp - rn)/(rp + rn)$, in which e = percentage error, rp = sum of reacting values of positive radicles, and rn = sum of reacting values of negative radicles. In aplying this formula to many waters silicon, iron, and aluminum should be omitted, the assumption being, as stated above, that these substances are present as colloidal oxides. Usually under most favorable conditions e will not exceed 5 in numerical value for waters containing a hundred or more parts per million of dissolved solids and may generally be expected to be 2 or less. A value of e in excess of 2 will indicate (1) a blunder in analysis or calculation; (2) if negative, the presence of iron, aluminum or some undetermined positive radicle; or (3) if positive, the presence of silicate or some undetermined negative radicle.

Practically all analyses, unless adjusted by the analyst, show some percentage of error, and in attempting to express the analysis as a perfect representation of the balance that actually exists the problem of dealing with this error arises. Four courses are possible: the error may be proportionately distributed among all the constituents by calculation; it may be assumed to lie in the determination of one basic radicle and one acid radicle, and may be divided equally between the two; it may be assumed to lie entirely in the determination of one radicle, such as carbonate or bicarbonate; or it may be retained without any attempt to correct it, in which case one property cannot be deduced.

The choice between these methods must be left to individual judgment. In the writer's opinion, the last method is generally unnecessary; if the error is so large that it cannot reasonably be adjusted in deducing a formula designed for preliminary study and classification it is presumably serious enough to invalidate the analysis for detailed study. The statement of the analysis in the ionic form and in reacting values by weight should of

[11] Stabler, Herman, U. S. Geol. Survey Water Supply Paper 274, p. 168, 1911.

course not be tampered with, but the error may reasonably be adjusted in the statement of reacting values by per cent. and in the properties deduced therefrom. In some types of water the error may be assigned with considerable confidence to one or two constituents. Thus, the methods of determining the alkalies and carbonate and bicarbonate are somewhat less reliable than those used for the other common constituents, and if the water contains a large proportion of any of these radicles the error may safely be adjusted among them. In many waters, however, the purely mathematical method of distributing the error proportionately is most satisfactory. For example, if the basic radicles total 150 and the acid radicles 151, each constituent in the first group may be divided by 300 and each in the second by 302, thus reducing each group to a 50 per cent. basis. Providing the original unbalanced analysis is given and the method of adjustment stated the exact manner in which balance is arbitrarily secured seems comparatively unimportant.

For example, the analytical error in the analyses discussed on page 29 may be found by reference to the statement in direct reacting values. In analysis *A* the acid radicles exceed the basic numerically by 3.58, in *B* by 0.85, and in *C* by 17.47, while in *D* the basic exceed the acid by 0.35. These differences represent percentage errors (e) of .95, .11, 1.6, and .03, respectively. In analyses *B* and *D* the error is so small that it does not appear in the statement of reacting values by per cent. In *A* and *C* it has been distributed proportionately among all the radicles, though in *A* there is some reason to suppose that it lies chiefly in the sodium and the bicarbonate figures.

CONSTITUENTS FOUND BY ANALYSIS.

In the accompanying table are shown most of the radicles that have been detected in natural waters, together with their reaction coefficients. The radicles are arranged according to their fundamental chemical relationships in the five groups already described. The grouping of the positive radicles is based on the relationships formulated by the periodic law; the grouping of the nega-

tive or acid radicles is based upon the strength of their acids, or, more properly, on the degree to which they ionize in dilute solution. As the acids form a continuous series from strong to weak the line of demarcation must be to a certain extent arbitrary. For certain purposes it may be found convenient to subdivide these groups and the properties in which they participate; salinity for example may be subdivided into chloride and sulphate salinity. Such elaborations may easily be made, but it must be recognized that the character formula is intended primarily for broad classification and preliminary study, and that in de-

POSITIVE AND NEGATIVE RADICLES AND THEIR VALENCES AND REACTION COEFFICIENTS.[1]

Positive Radicles.	Valence.	Reaction Coefficients.	Negative Radicals.	Valence.	Reaction Coefficients.
Alkali:			*Strong acid:*		
Sodium (Na)	1	.0435	Nitrate (NO_3)	1	.0161
Potassium (K)	1	.0256	Chloride (Cl)	1	.0282
Lithium (Li)	1	.1441	Bromide (Br)	1	.0125
Rubidium (Rb)	1	.0117	Iodide (I)	1	.0079
Caesium (Cs)	1	.0075	Sulphate (So_4)	2	.0208
Ammonium (NH_4)	1	.0554	Thiosulphate (S_2O_3)[4]	2	.0178
Alkaline earth:			*Weak acid and hydroxide:*		
Barium (Ba)	2	.0146	Fluoride (F)[4]	1	.0526
Strontium (Sr)	2	.0228	Phosphate (PO_4)	3	.0316
Calcium (Ca)	2	.0499	Arsenate (AsO_4)	3	.0216
Magnesium (Mg)	2	.0822	Sulphite (SO_3)	2	.0250
			Sulphide (S)	2	.0624
Hydrogen and metal:			Acid sulphide (HS)	1	.0302
Hydrogen (H)[2]	1	.9921	Carbonate (CO_3)	2	.0333
Copper (Cu)	2	.0315	Bicarbonate (HCO_3)	1	.0164
Zinc (Zn)	2	.0306	Borate (B_4O_7)	2	.0128
Cadmium (Cd)	2	.0178	Metaborate (BO_2)[3]	1	.0232
Aluminum (Al)[3]	3	.1107	Silicate (SiO_3)[3]	2	.0262
Lead (Pb)	2	.0096	Hydroxide (OH)[5]	1	.0588
Manganese (Mn)	2	.0364			
	3	.0546	*Gases:*		
Iron (Fe)[3]	3	.0537	Carbon dioxide (when forming		
	2	.0358	HCO_3)		.0227
Nickel (Ni)	2	.0341	Hydrogen sulphide (when forming HS)		.0293
Cobalt (Co)	2	.0339			

[1] Computed on basis of 1916 atomic weights.
[2] Hydrogen (H) = true acid radicle.
[3] More commonly present as colloidal oxide.
[4] May be classed as either weak or strong acid.
[5] Hydroxide (OH) = true basic radicle.

tailed study the peculiar properties of each radicle should be taken into account directly.

Dissolved gases are probably present in most waters, but unfortunately they are not often determined by the analyst and their significance and relations in natural solutions have not been exhaustively studied. Carbon dioxide and hydrogen sulphide are common dissolved gases that have an important effect on the properties of the solution and may determine its activity as a geologic agent. They may be regarded as free weak acids, which contribute a measure of acidity to the solution, but which under favorable conditions may enter into the chemical system as components, like all weak acids, of alkalinity. Because of their rather indeterminate value it seems best for the present to group their potential reacting values as a separate property, which is not to be included in the summation of the properties to a hundred but is to be expressed as a per cent. of the sum of all the other properties. This property may be termed subalkalinity.

SIGNIFICANCE OF THE PROPERTIES DEDUCED FROM THE ANALYSIS.

The "properties" entering into the character formula devised by Palmer have so far been considered only as properties of constitution, or numerical indices of proportional reacting values. However, inasmuch as they are indices of reacting values they are true properties of reaction, and afford an indication of the behavior of the water under most natural conditions. The activity or reactive quality of a water obviously depends first on the nature and proportional amount of the mineral constituents dissolved in it; this is shown in detail in the statement of reacting values and is summed up in the character formula. Considered from a different standpoint, the type of action of a water may depend also on the concentration of the several constituents, or the extent to which each approximates its solubility product. If a water is not saturated with respect to calcium carbonate, for example, it may be expected to take more into solution, and if

through change in conditions it becomes supersaturated, calcium carbonate will be deposited. The question as to whether a water will dissolve or deposit calcium carbonate depends primarily of course on the concentration of the Ca and CO_3 radicles and the partial pressure of CO_2, and to some extent on the concentration of other radicles in the solution; but these factors are influenced largely by conditions of temperature and pressure which usually are not constant and in a great many cases, including most groundwaters, can be only approximated. Despite the frequent desirability of determining them accurately, in many cases if the concentration of two radicles is close to the saturation point of the salt represented by those two radicles the best criterion as to whether the water is dissolving or depositing the salt is field evidence. The concentration of the several radicles is not represented in the character formula, and must be studied in the statement by weight or by direct reacting values.

In discussing the properties of a solution it is important to distinguish between its properties of reaction, or its behavior when brought into contact with chemical reagents, and its properties of condition, such as the degree of ionization, hydrolysis, etc., of its constituents. The properties of reaction depend wholly on the nature and proportional amount of the constituents, and are the chief consideration of analytical chemistry; properties of condition depend on a variety of factors and are the chief consideration of physical chemistry. The conceptions of physical chemistry explain many of the reactions with which analytical chemistry is concerned, but the determination of the physical properties of the solution is not essential to its chemical analysis. The distinction between the two types of properties is clearly made by Ostwald in the last of the following paragraphs:[12]

"Although different acids and bases are dissociated into their ions in very different degree, the comparison of equivalent solutions gives the same result. Thus, a solution containing 36.46 gms. or one equivalent of hydrochloric acid requires the same quantity of a given solution of

[12] Ostwald, W., "Foundations of Analytical Chemistry," pp. 127–129, 1908.

baryta water for neutralization as one containing the equivalent quantity of dilute acetic acid, *i. e.*, 60.04 gms. of the latter. It has been already mentioned that acetic acid is dissociated to the extent of less than 10 per cent., and one might therefore expect that less than one tenth of the above baryta water would suffice for the neutralization of its hydrogen ions. The same amount of baryta is, however, required as in the case of the hydrochloric acid; hence it follows that, in the titration with baryta or any similar basic liquid, it is not merely the immediately free hydrogen ions which come into play, but every hydrogen ion which can be set free from the acid in question, provided that the latter is capable of complete ionic dissociation. . . .

"These considerations apply of course to all acids and also to all bases. The point can be expressed generally by saying that not only the ions actually existing as such at the moment are brought into play by neutralization, but the whole mass of ions which can be formed under the conditions of the analysis, *i. e.*, both the actual and the potential ions together.

"It is easy to see that the same considerations can be applied to every other chemical process in which definite ions are measured analytically. In every case a particular ion is withdrawn from the solution, whereby its equilibrium with its own compound present is disturbed; more ion is thus set free, so long as any of that compound remains, and hence the potential ions, too, are always measured by the ordinary analytical methods.

"The measurement of the actual concentration of a definite ion under given conditions is quite a different task, with the solution of which we need not concern ourselves here, since it is not at present looked upon as pertaining to analytical chemistry."

The same considerations apply to natural waters. Thus, alkalinity in the physical chemical sense means an excess of hydroxyl ions over hydrogen ions, but in the analytical sense means total weak acid, or the potential as well as the actual ions. The former is a property of condition, the latter a property of constitution or reaction. According to the ionic conception a salt like Na_2CO_3 ionizes to some extent and hydrolyzes to a greater extent; and the products of hydrolysis, $Na—OH$ and $H_2—CO_3$, ionize in turn. Since the former ionizes to a marked degree and the latter only slightly the solution is characterized by an excess of hydroxyl ions over hydrogen ions. Such a solution is an active solvent of silicate rocks, a fact which may be ascribed to this

excess of hydroxyl ions; and although this excess is destroyed as the solution reacts with the rocks it is immediately restored again by ionization and hydrolysis of the unchanged salt. As this process goes on until all of the original Na_2CO_3 is destroyed, the important consideration from the geological standpoint is evidently the total concentration of the Na and CO_3 radicles rather than the degree of ionization and hydrolysis, which chiefly determine the relative concentration of hydroxyl and hydrogen ions in the solution at a given moment. Determination of the physical properties of the solution may be of value in many studies, but it is important to realize that these properties are not properties of reaction, and that they do not enter into the character formula under consideration.

EXAMPLES OF THE INTERPRETATION OF WATER ANALYSES.

The significance and working value of water analyses in certain lines of geologic work may become more clear if a few examples, selected to show the advantages and the limitations of the system of interpretation proposed by Palmer, are briefly considered. Any analysis may of course be studied from several view points and it is impossible to demonstrate in a brief paper the value of a comprehensive system of interpretation, but it is hoped that the examples chosen for consideration may prove suggestive. Examples 1 and 2 are intended to illustrate the comparison and classification of waters, and examples 3 and 4 the manner in which the geologic association of waters may be deduced from their analyses. Example 5 illustrates the possibility of estimating the activity of the water from its analysis.

The most suitable form of statement for the analysis depends largely on the character of the study in hand, and for certain purposes the statement in ionic form may be sufficient and entirely satisfactory. Thus, if a large number of waters are to be examined for their potash content and their analyses compared on this basis the figure representing the weight of the potassium radicle may be an adequate criterion for comparison.

If the chemical nature of the water is to be the basis of comparison, however, it is highly desirable to translate the analysis into chemical terms, and to use a form of statement like that in reacting values.

Preliminary classification and general study, especially where a large number of analyses are concerned, are greatly facilitated if this detailed statement is reduced to the formula represented by the properties of reaction. The formula characterizes the water and affords an indication of its behavior under most conditions. For example, a water in which primary alkalinity is prominent, (1) is commonly derived from and associated with igneous rocks; (2) is an active solvent of silicate rocks; (3) requires no soda-ash in softening for industrial or domestic use; (4) is non-corrosive under boiler conditions, deposits only soft scale, has a tendency to foam, etc. A water in which secondary salinity is prominent, (1) is generally derived from and will contribute to the formation of marine sediments; (2) is permanently hard and requires soda-ash in softening; (3) has corrosive tendencies and deposits hard scale under boiler conditions, etc. Similarly, tendencies due to other properties, and the modification of these tendencies by reason of associated properties, can be distinguished, and their relative prominence can be approximated. On the other hand, conclusions can not be carried too far on the basis of group tendencies alone. For example, high salinity if due chiefly to chloride generally indicates a water of marine antecedents, but if due chiefly to sulphate suggests a meteoric water of the type common in the arid regions of the west; secondary salinity if contributed largely by magnesium marks a corrosive water, but if due entirely to calcium a water that is probably not corrosive. That the properties as defined are true chemical properties is indicated by the fact that they may be determined directly in the solution as a whole, but it must always be borne in mind that they are based on groups of radicles rather than upon individuals.

Example 1—Waters of the Midway Oil Field, California.—In the Midway oil field many lenticular sands carrying water

under high pressure are present in the strata above, in, and below the oil measures. In developing the field it is essential to prevent the water from invading the oil sands, and although in general this is done while the well is being drilled, occasionally water from an unknown source may later suddenly flood the well. It was suggested that a chemical survey of the waters might show differences in character which would permit the identification of the horizon of a water from its analysis, and study by the writer has shown that fairly regular variations in character occur with depth and also with distance from the outcrop.[13] By calculating the formula of the properties of reaction in the seventy-five analyses available, the writer was enabled to arrive at a much clearer conception of this variation in two directions than would have been possible if the analyses in the ionic form alone had been considered.

The following analyses represent waters in the same general zone but at different distances from the outcrop, being taken from four wells along a straight line somewhat oblique to the direction of dip. Sample *A* was taken about 9,000 feet east of the outcrop, and *B*, *C*, and *D* about 6,000, 12,500, and 18,300 feet respectively east of *A*. The depth of the zone ranges from 1,334 feet at *A* to 2,924 feet at *D*.

In Table I. are shown the analyses of these waters in the ionic form in parts per million. By comparison of the analyses in this form it is seen that the concentration of *D* is about three times that of *A*, that the alkalies increase in about the same proportion, but that the alkaline earths in *D* are about 34 times as great as in *A*. The chloride in *D* is about five times that in *A*, but sulphate shows an irregular decrease from *A* to *D*. Carbonate and bicarbonate in *D* are roughly one twentieth as great as in *A* but the decrease is not regular. Iron and aluminum show no significant variation; silica shows a fairly regular decrease from *A* to *D*. Simple comparison of the weights of the radicles pres-

[13] Rogers, G. Sherburne, Preliminary report on the chemical relations of the oilfield waters in the San Joaquin Valley oil fields, California, U. S. Geol. Survey Bull. —, in press.

ent thus discloses certain well-marked differences, but is tedious and difficult because each constituent varies at a different rate, and unsatisfactory because it gives no direct insight into the quality of the waters.

TABLE I.

ANALYSES OF GROUNDWATER FROM THE MIDWAY OIL FIELD, CALIF.
(PARTS PER MILLION.)

	A.	*B.*	*C.*	*D.*
Sodium (Na)	4,188	8,437	10,548	11,656
Potassium (K)	52		72	
Calcium (Ca)	31	163	772	1,281
Magnesium (Mg)	21	94	570	443
Iron (Fe)	.02	.04	.1	
Aluminum (Al)	5.2		8.4	
Sulphate (SO_4)	11	3	34	4.3
Chloride (Cl)	4,593	11,123	19,624	21,415
Carbonate (CO_3)	108	0	0	90[1]
Bicarbonate (HCO_3)	3,477	4,270	573	
Silica (SiO_2)	125	108	43	39
	10,846.22	22,031.04	31,953.5	34,928.3

In Table II. are shown the same analyses recast into reacting values. The first four columns show the direct reacting values by weight and the last four show them in per cent. Both forms bring out the chemical values of each constituent and make possible a study of their capacities for reaction. For example, the ionic statement in Table I. indicates that water *A* contains only two thirds as much magnesium as calcium, but Table II. shows that the value of the magnesium is considerably greater. Similar changes in apparent relationship may be observed by comparing the weights and values of other constituents.

For purposes of general comparison the second part of Table II., in which the factor of concentration is eliminated, is especially convenient, and a detailed study of the proportional values of the several constituents is illuminating. It will be observed that in analyses *A* and *B* the strong bases (alkalies) are very high and exceed the strong acids (chloride and sulphate). Con-

[1] Reported and calculated as carbonate but includes bicarbonate.

sequently a certain value of the alkalies, and the total value of the alkaline earths (calcium and magnesium), are balanced by the weak acids (carbonate and bicarbonate). In analysis *B*, for example, the 40.9 per cent. of strong acids balances with 40.9 per

TABLE II.

ANALYSES OF WATERS IN TABLE I. RECAST INTO REACTING VALUES, IN WEIGHT AND IN PER CENT.

	Reacting Values (Weight).				Reacting Values (Per Cent.).			
	A.	*B.*	*C.*	*D.*	*A.*	*B.*	*C.*	*D.*
Alkalies								
rNa	182.18	367.01	458.83	507.01	48.8	47.9	42.0	41.7
rK	1.33		1.84		.3		.2	
Earths								
rCa	1.55	8.13	38.52	63.92	.4	1.1	3.5	5.3
rMg	1.73	7.76	46.85	36.41	.5	1.0	4.3	3.0
Strong acid								
rSO_4	.23	.06	.71	.09	.1		.1	
rCl	129.52	313.66	553.40	603.90	34.0	40.9	49.1	49.7
Weak acid								
rCO_3	3.60			3.00	.9			.3
$rHCO_3$	57.02	70.03	9.40		15.0	9.1	.8	
	377.16	766.65	1,109.55	1,214.33	100.0	100.0	100.0	100.0

cent. of alkalies, leaving 7 per cent. of alkalies to balance an equal value of weak acids, which in turn leaves 2.1 per cent. of the weak acids in equilibrium with the 2.1 per cent. of earths. In analyses *C* and *D*, however, the reverse relation exists; the strong acids exceed the alkalies and balance a partial value of the earths, only a small proportion of the latter balancing with weak acid. Thus, in analysis *C* the 42.2 per cent. of alkalies balances an equal value of strong acids and leaves 7 per cent. of the latter to balance 7 per cent. of earths, the remaining 0.8 per cent. of earths being in equilibrium with 0.8 per cent. of weak acids. These relations, which are fundamental in determining the quality of a water, are summed up as properties in Table III. For purposes of comparison the properties of ocean water are added.

The analyses as stated in Table II. are rationally epitomized and their comparison is simple. It is evident that waters *A* and *B* belong in class 1, and are very different in chemical character

TABLE III.

PROPERTIES OF REACTION AND CONCENTRATION OF THE WATERS WHOSE ANALYSES APPEAR IN TABLE I. AND OF OCEAN WATER.

	A.	*B.*	*C.*	*D.*	Ocean Water.
Primary salinity	68.2	81.8	84.4	83.4	78.6
Secondary salinity			14.0	16.0	21.1
Primary alkalinity	30.0	14.0			
Secondary alkalinity	1.8	4.2	1.6	.6	.3
	100.0	100.0	100.0	100.0	100.0
Concentration (parts per million)	10,846	22,031	31,953	34,928	35,000

from *C* and *D*, which together with ocean water belong in class 3 (see Fig. 1). The essentially regular decrease in primary alkalinity from *A* to *B*, and in secondary salinity from *D* to *C*, indicates that at some point between *B* and *C* a water of class 2, characterized by only primary salinity and secondary alkalinity, would be found. The explanation of this remarkable change in the character of the water from the same zone in a distance of about three miles is found by comparison of water *D* with ocean water. The essential similarity between the two indicates that *D* is a trapped marine (connate) water, only slightly altered, and that *C*, *B* and *A*, lying respectively nearer the outcrop, have undergone increasing modification through mixture with infiltrating rain water charged principally with carbonates.[14] The form of statement employed in Table III., taken in connection with the percentage reacting values of the individual radicles, discloses a series of differences that are not easily observed in the ionic form of statement used in Table I. For detailed study Table II. is essential but for preliminary classification and comparison Table III. is convenient and suggestive.

Example 2—Waters of the Ozark Uplift.—C. E. Siebenthal in his exhaustive study of the origin of the zinc and lead deposits of the Joplin region has considered in detail the character of the

[14] In detail the water represented by analysis *D* differs from ocean water in containing practically no sulphate and in the fact that it carries less magnesium than calcium. These differences are considered in example 4, p. 82.

groundwaters of that area. He finds certain marked differences in character between the waters near the center of the Ozark uplift and those near the border, which he attributes to differences in the freedom of the circulation. His exposition of the summarized evidence, quoted below, is illuminating.[15]

"The analytical comparison of waters from deep wells in the limestone area of the Ozark uplift with waters from deep wells in the Pennsylvania shale area surrounding the uplift, though all these wells draw their supply from the Cambrian and Ordovician rocks, reveals some interesting differences, which can best be brought out by a parallel representation of the properties of a short series of waters from each area. . . .

COMPARISON OF THE GEOCHEMICAL PROPERTIES OF WATERS FROM INTERIOR AND BORDER WELLS OF THE OZARK UPLIFT.[16]

Properties.	Border Wells.		Ocean Water.	Interior Wells.	
	Claremore.	Brunswick.		Oronogo.	Carthage.
Primary salinity	82.2	76.2	78.6	10.2	10.6
Secondary salinity	16.6	20.4	20.8	2.2	.6
Primary alkalinity					
Secondary alkalinity	1.2	3.4	.6	87.6	88.8
Total reacting value or concentration (parts per million)	74.0	269.0	1,211.0	7.0	7.0
Chloride salinity	98.8	86.4	90.0	10.2	4.4
Sulphate salinity	0	10.2	9.2	2.2	6.8
Ratio of *r*Ca to *r*Mg	1 : .53	1 : .72	1 : .53	1 : .62	1 : .71

"As will be observed, the border well waters are high in primary salinity but show minor proportions of secondary salinity and alkalinity. They are likewise high in chloride salinity but low in sulphate salinity. They are therefore primary waters, in which the alkali bases predominate, and resemble brines. . . . To show this close relationship in quality [of water from the Brunswick well to ocean water] the character outline of ocean water according to Dittmar's analysis is included in the table. The water of the Claremore well is also very similar in character to ocean water, although, of course, the waters of both the Claremore and the Brunswick wells are more dilute than sea water. The concentration or total reacting value of the border waters is never-

[15] Siebenthal, C. E., "Origin of the Zinc and Lead Deposits of the Joplin Region," U. S. Geol. Survey Bull. 606, pp. 155–156, 1915.

[16] A portion of the table given by Siebenthal. His table is designed to show the extremes of variation, between which all gradations are found.

theless high as compared to that of the interior waters, which range from one fourth to one thirtieth that of the border wells. The interior wells are low in primary and secondary salinity but high in secondary alkalinity; chloride salinity is also low and sulphate salinity is a little higher. They are secondary waters, that is, they are waters in which the alkaline-earth bases predominate. Another difference not brought out in the table is that the waters of the border wells are charged with hydrogen sulphide, whereas the waters of the interior wells contain little, if any, of this gas.

"These differences are directly attributable to the artesian circulation of the dome. When sediments are laid down upon the floor of the sea they are saturated with sea water, which remains in the pore spaces of the sediments as connate water until they are elevated into land, when it becomes a part of the circulating ground water. Diluted with atmospheric water, the salt is gradually carried away, and the ground water is 'sweetened' and charged with elements dissolved from the sediments.

"As the Ozark artesian circulation developed and, with erosion of the Pennsylvanian shale, gradually extended itself down the slopes of the dome, the circulation in the rocks near the center was continually losing a portion of its chloride salinity and taking on secondary alkalinity (earthy carbonates), owing to dilution of the connate water and to solution of the country rock. This being so, we should expect that the water of wells near the center of the dome would show least chloride salinity and that of wells out in the Pennsylvanian shale area, beyond the border of the uplift, where the circulation beneath is practically impounded, would show the greatest chloride salinity, the water of the wells between showing degrees of chloride salinity corresponding to the positions of the wells. This, making allowance for local variations, is undoubtedly the case."

Example 3—Surface Waters in Northeastern Oregon.—An example of the value of water analyses in preliminary geologic work is contained in a report by Walton Van Winkle on the quality of the surface waters of Oregon.[17] Although Van Winkle's work was primarily a study of the composition of the waters he was able by the use of Palmer's system to correlate the quality of the waters with the type of rock over which they flow. In the drainage basins of most of the rivers studied primary (volcanic) rocks predominate and all but one of these waters are characterized by primary alkalinity. This is illus-

[17] U. S. Geol. Survey Water Supply Paper 363, 1914.

trated by the analyses of the waters of Umatilla and Grande Ronde rivers given in the following table. It was found however that Wallowa River, a tributary of the Grande Ronde which was likewise supposed to have its source in a region of volcanic rocks, is secondary saline in character and exhibits high secondary alkalinity. Van Winkle's account of the quality of this water, of his deductions therefrom, and of the geologic discovery which resulted may be quoted in full.[18]

"The analytical data [on the water of Wallowa River] are of considerable scientific interest, as they indicate that the prevailing opinion regarding the rocks of this region is erroneous, the water not being such as would come from volcanic formations. The water is characterized by secondary salinity, the proportion of calcium being exceptional for a surface water of the Northwest. The ratio of magnesium to calcium is lower than that of any other surface water in the United States whose mineral composition is known to the author and is a ratio that might be found in water draining limestones fairly free from magnesium. . . .

MINERAL ANALYSES AND GEOCHEMICAL CLASSIFICATION OF WATERS FROM RIVERS IN NORTHEASTERN OREGON.[19]

	Umatilla River at Gibbon.	Grande Ronde River at Elgin.	Wallowa River at Joseph.
Properties of reaction in per cent:			
Primary salinity	21.7	15.0	19.3
Secondary salinity			.5
Primary alkalinity	21.8	20.0	
Secondary alkalinity	56.5	65.0	80.2
Mineral analysis in parts per million:			
Sodium (Na)	12	7.8	3.8
Potassium (K)		2	1
Calcium (Ca)	8.9	10	15
Magnesium (Mg)	2.3	2.8	.6
Iron (Fe)	.05	.25	.02
Sulphate (SO_4)	6.0	5.3	8.5
Chloride (Cl)	4.0	1.6	.55
Nitrate (NO_3)	.36	.75	.21
Bicarbonate (HCO_3)	45	54	47
Silica (SiO_2)	41	30	10
	96.61	86.50	62.68

"The meager information at hand when this investigation was begun indicated that only Tertiary lavas and other volcanic rocks, and no

[18] *Op. cit.*, pp. 65 and 66.

[19] *Op. cit.* Compiled from tables on pages 62, 64, 68, and 127.

Paleozoic, Triassic, or Jurassic rocks were exposed in the upper basin [of Wallowa River]. The pronounced calcareous nature of the water, however, showed the error of these assumptions, and inquiries sent to mining engineers and others brought forth the following information: . . . Limestone occurs in patches [the Wallowa basin] and in places shows a thickness of 500 feet or more. Other minor exposures of calcareous rocks have been found in Wallowa County but not in Wallowa River Basin. In places the streams have cut entirely through the limestone, which almost everywhere crowns the ridges."

Example 4—Waters of the Coalinga Oil Field, California.—Another example of the extent to which the composition of water is influenced by its geologic associations is found in the Coalinga oil field, California.[20] Conditions in the Coalinga field are similar to those in the Midway field described above, and a chemical study of the waters revealed marked differences in character between those near the surface and those near the oil zone. The surface waters and normal groundwaters are high in sulphate, whereas those near the oil measures carry little or no sulphate but generally contain a high concentration of carbonate. These differences are believed to be due to reaction between the water and constituents of the oil or gas, whereby the sulphate is reduced to sulphide and a portion of the hydrocarbon material is oxidized to carbonate. In studying this replacement of sulphate by carbonate the properties of reaction are of subordinate importance and the main interest attaches to the respective proportions of the two radicles; but as described above the waters also change in character with distance from the outcrop and a comprehensive study of their relations therefore can not be based solely upon isolated ratios.

The following analyses represent waters from different depths in four adjoining wells in the southwest corner of the Coalinga field. Sample *A* is from a depth about 800 feet, a distance of about a thousand feet above the oil zone; *B* occurs at 450 feet above the oil; *C* occurs 150 feet below a sand carrying heavy tar and 250 feet above the oil zone; and *D* represents water from a sand 25 feet below the oil zone.

[20] Rogers, G. S., *op. cit.*

ANALYSES OF WATER FROM DIFFERENT DEPTHS IN THE COALINGA OIL FIELD.

	A.	B.	C.	D.
PROPERTIES OF REACTION IN PER CENT.:				
Primary salinity	59.0	67.0	36.2	63.8
Secondary salinity	36.8	18.6		
Primary alkalinity			50.8	30.8
Secondary alkalinity	4.2	14.4	13.0	5.4
Per cent. of rSO_4 in $rSO_4 + rCl$	80.0	67.0	27.6	0.6
Ratio of rCO_3 to rSO_4	.05	.26	6.38	90.5
REACTING VALUES IN PER CENT.:				
Alkalies:				
Sodium (rNa)	29.5	33.5	43.5	47.3
Potassium (rK)				
Alkaline earths:				
Calcium (rCa)	12.7	7.9	1.9	1.4
Magnesium (rMg)	7.8	8.2	4.6	1.3
Strong acids:				
Sulphate (rSO_4)	38.3	28.7	5.0	.2
Chloride (rCl)	9.6	14.1	13.1	31.7
Weak acid:				
Carbonate (rCO_3)	2.1	7.6	31.9	18.1
CONSTITUENTS IN PARTS PER MILLION:				
Sodium (Na)	804	933	717	2,872
Potassium (K)				
Calcium (Ca)	303	193	27	75
Magnesium (Mg)	112	121	40	44
Iron oxide (Fe_2O_3) and Alumina (Al_2O_3)	14	19	3	56
Sulphate (SO_4)	2,181	1,673	170	23
Chloride (Cl)	404	606	332	2,961
Carbonate (CO_3)	76	282	686	1,435
Silica (SiO_2)	54	249	95	67
	3,948	4,076	2,070	7,533

In these analyses the most striking variations and those most important from an economic standpoint are shown by the carbonate and sulphate values. This is illustrated by the carbonate-sulphate ratio, which increases from .05 in the highest water to 90.5 in the lowest, in which sulphate is practically lacking. This decrease in sulphate is also shown by the figures representing the sulphate salinity ratio (per cent. of rSO_4 in $rSO_4 + rCl$), which is 80 in the highest water and 0.6 in the lowest.

It will be noted that the two upper waters are secondary saline in character and therefore belong to class 3, whereas the two lower are primary alkaline and fall in class 1. This separation

into two classes is borne out by a more detailed study of the analyses, which indicates that the most marked changes take place near the tar sand, or between waters *B* and *C;* the two upper waters, *A* and *B,* are very similar and *D* differs from *C* chiefly in its higher chloride. Sulphate shows the most pronounced and regular variation, its value decreasing from 38 per cent. in the highest water to .2 per cent. in the lowest. The carbonate value rises from 2 per cent. in the first water to 32 per cent. in the third, and then owing to the great increase in chloride in the lowest water decreases to 18 per cent., although in actual amount it is higher in the fourth water than in the third. Chloride increases only slightly down to the third water but in the lowest is markedly higher. The alkalies increase regularly with depth and the alkaline earths decrease. The concentration shows a slight rise in the second water, a fall in the third and a marked rise in the fourth. The lower concentration of the third water is presumably due to the formation of the relatively insoluble carbonates of the alkaline earths, which are precipitated. This also explains the loss of alkaline earths and the rise of alkalies in the third water. If actual amounts are considered instead of percentages it will be noted that the earths fall off even more abruptly whereas the alkalies show little increase. To sum up these variations, alkalies, chloride, carbonate and the concentration value increase with depth, whereas alkaline earths and sulphate decrease. In the formula representing the properties of reaction the decrease of earths is indicated by the decrease of the secondary properties and the increase of alkalies by increase of the primary properties; the increase of carbonate in waters *A, B* and *C* is indicated by increase of alkalinity and the predominance of chloride in the lowest water by the predominance of salinity. The important changes that do not appear in the formula are the practical disappearance of sulphate and the increase in concentration, and these factors must be sought directly in the detailed analyses.

Example 5—Acid and Alkaline Waters.—It is generally assumed that all waters at one time or another exert a solvent effect

upon the rocks with which they come in contact, thus deriving their load of dissolved mineral matter. The constituents already in solution naturally determine to a large extent the degree of activity of the water, and extreme types of geologically active solutions are presented by the acid and the permanently alkaline (primary alkaline) waters—those containing free acid and those which are solutions of alkali carbonate. The commonest free acid in natural waters is sulphuric acid derived through the oxidation of metallic sulphides. Waters characterized by permanent alkalinity probably originate in several ways, and although their activity is less pronounced than that of acid solutions it is none the less important. Hilgard, in a paper entitled "The Geologic Efficacy of the Alkali Carbonate Solution," summed up many years ago the chemical and physical effects as follows:[21]

"The powerful chemical effects of alkali carbonates upon the rock ingredients hardly require discussion. From the radical results obtained in their fusion with silicates in the laboratory, to the more gentle action exerted by alkaline carbonated mineral waters in dissolving and redepositing silica, whether in the form of sinter or of gold-bearing quartz veins, there is a wide range of possible and probable reactions, less incisive than the former, and more so than the latter, that will readily explain a good many recondite as well as common phenomena of metamorphism as well as of vein formation, without resort to violent hypotheses. . . . The alkali carbonates seem much more likely [than the alkali earth carbonates] to be an efficient agency, especially in view of their more decided character in the excitation of electrolytic action.

"Scarcely less important than the multifarious chemical effects that may be produced by the superacid alkali-carbonate solutions, are the physical effects which they may and doubtless have exerted upon the consolidation and lithification of sedimentary deposits containing clay. The peculiar 'puddling' effect of dilute solutions of sodium carbonate upon clays, to which I first called attention in 1872, is probably one of the most active agencies in converting ancient soils and other clayey alluvium into the compact masses of shales and hardened clays which are specially characteristic of all coal-bearing formations."

Assuming, then, that it is desirable to determine from the analysis if a water contains free acid on the one hand, or alkali

[21] *Amer. Jour. Sci.*, 4th ser., Vol. 2, pp. 100–107, 1886.

carbonate on the other, the question as to how this may be done arises. Obviously, simple inspection of the analysis in the ionic form will not suffice, and some kind of calculation involving chemical values rather than physical weights is essential.

Although many examples are available, analyses of two mine waters studied by E. S. Bastin in an investigation of the conditions of ore deposition at Tonopah, Nevada, may be selected, because of the importance in this instance of determining the nature of the reactions between the waters and the rocks and ores. In the following table are shown the analyses expressed in parts per million by weight and in reacting values by per cent. The character formula summarizing the latter form of statement is also shown. It will be noted that analysis *A*, as stated by weight, shows merely what might be called a sodium and calcium sulphate and carbonate water. In the statement by reacting

ANALYSES OF MINE WATERS FROM TONOPAH, NEVADA.

	A.		*B.*	
Properties of reaction:				
Primary salinity	61.0		26.8	
Secondary salinity			57.8	
Tertiary salinity			15.4	
Primary alkalinity	4.2			
Secondary alkalinity	24.8			
Tertiary alkalinity	10.0			
	100.0		100.0	
Constituents.	By Weight.	Reacting Values in Per Cent.	By Weight.	Reacting Values in Per Cent.
Sodium (Na)	80	31.4	135	12.7
Potassium (K)	5	1.2	12	.7
Calcium (Ca)	20	9.1	249	27.1
Magnesium (Mg)	4.4	3.3	10	1.8
Iron (Fe)	3	1.0	7	.5
Aluminum (Al)			3	.7
Manganese (Mn)	12	4.0	75	5.9
Hydrogen (H)				(.6)
Sulphate (SO_4)	106	21.0	1,019	46.0
Chloride (Cl)	35	9.5	65	4.0
Carbonate (CO_3)	36	11.5	None	
Arsenate (AsO_4)			Trace	
Bicarbonate (HCO_3)	51	8.0	None	
Silica (SiO_2)	15		15	
Total	367.4	100.0	1,590	100.0

value, however, it is apparent that the alkalies exceed the strong acids and must therefore be partly in equilibrium with weak acid radicles. The water, in other words, is partly an "alkali carbonate solution" and as shown in the formula is characterized by 4.2 per cent. of primary alkalinity.

Analysis *B*, as stated by weight, shows a water that might be termed a sodium calcium sulphate water, differing from *A* chiefly in the absence of carbonate. The fact that it is very different from *A* in its nature and properties is not readily apparent in this form of statement, but becomes obvious upon inspection of the reacting values. All of the alkalies, earths, and metals are in equilibrium with strong acid radicles, and there is also a slight excess of acid radicle over basic which is presumably due to the presence of free acid, a condition that can not be ascertained from the analysis by weight without recalculation. This solution gives an acid reaction (to methyl orange), as would be expected from the presence of rather weak bases (metals) in equilibrium with strong acid, as well as from the inferred presence of the hydrogen radicle.

CONCLUSION.

The method of stating and interpreting water analyses suggested by Chase Palmer is based on the principle that natural waters are balanced chemical systems having definite properties, which may either be deduced from the ordinary analysis or determined directly in the solution. These properties therefore summarize the composition of the water and furnish a convenient basis for preliminary comparison and study, and at the same time afford a measure of the potency of the water as a geologic agent. In deducing the properties the analysis in the ionic form is first translated into reacting values, whereby the true chemical value of each radicle is expressed, and in order to eliminate the factor of concentration the value of each radicle is then reduced to a percentage of the sum of the values of all the radicles. This form of statement is a rational chemical characterization of the water, and aside from concentration, which must also be consid-

ered, affords the most satisfactory basis for detailed comparison now in use. As a basis for general chemical classification it is cumbersome because of the many items that must be considered, and this feature is overcome by Palmer at the expense of detail by grouping those radicles which are chemically most similar. The properties are then deduced by first balancing the chemically strong bases with the chemically strong acids, and then balancing the excess of chemically strong bases or acids with chemically weak acids or bases. This grouping and balancing results in the derivation of a few significant items (properties), which show at a glance the proportion of the chemical system that is relatively inert and unavailable and that which is relatively free and available, thus indicating the nature of chemical action of the water under many conditions.

It has been shown that in certain types of geologic problems the study of water analyses in the usual form (by weight) is inadequate, and that the use of a form expressing the chemical values of the constituents is essential. In practically all studies such a form of statement is at least highly desirable, and in most cases preliminary comparison and study are greatly simplified if based upon the formula consisting of the properties deduced from the analysis.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

GENESIS OF THE CHILEAN NITRATE DEPOSITS.

Sir:—I have read with much interest the paper by Messrs. Singewald and Miller on the origin of the Chilean nitrate that appeared in the March–April number of this journal.

For thirty-five years I have been familiar with the nitrate region, having been both manager of a nitrate oficina and examiner of new terranes, and for that reason believe that it will be of interest to state observations that I have made and the manner in which I explain the origin of the Chilean nitrates.

In Tarapacá, the region visited by Messrs. Singewald and Miller, the intimate relation existing between the location of the nitrate and the topography is at once apparent. The explanation which they give of this relation is the same that occurred to me when I first saw the nitrate pampa, and which doubtless has suggested itself to others; that is to say, the caliche represents an efflorescence of salts contained in the groundwater, which has come from the Andean range and carries in solution the salts which it has encountered in its path and deposits them by evaporation on reaching the coast range. Later I became familiar with the nitrate pampas of Taltal where the topographic conditions are entirely different. In Taltal the region between the Andes and the coast range is broken up by isolated ranges, between which are plains inclined in all directions, many of which

have no communication whatever with the Andes, and the underground waters of which, if indeed any exist, could not have come from very far. Nevertheless in these plains the most important nitrate deposits are frequently found on the slopes and sometimes on the very summits of the isolated hills that rise to elevations of several hundred meters above them. The occurrence of nitrate on hill tops is not merely a scientific curiosity, but of industrial importance in the case of flat-topped hills of considerable extent. In such cases, the steeper slopes between the deposits at the summit and those at the base contain no nitrate.

Under these conditions it is absolutely impossible that the nitrate has been brought from elsewhere by subterranean waters; it must have formed "in situ" on the summits themselves. Here suffices neither the theory of groundwater, nor of guano, nor of algæ, nor of decomposition of organic substances by microbes; the only source that the nitrate on the summits of isolated hills rising hundreds of feet above the plains could have had is the atmosphere. This is the theory of Pissis, according to which the nitric acid comes from the air and the sodium from the decomposition of the feldspathic rocks.

It is well known that nitric acid is encountered everywhere in the atmosphere in small quantity, whatever its origin may be. For that no special electrical theory is required. But this small quantity which is continuously renewed suffices in the course of centuries to form beds of nitrate, just as the carbonic acid of the air has formed beds of coal and as the authors of the paper under discussion say the minute quantity of nitrate dissolved in the groundwater has formed the nitrate beds.

The origin of the soda involves nothing more than the decomposition of the feldspathic porphyrites. In other words, those rocks *which are found wherever there is nitrate* are transformed often to a depth of several feet into a white or yellowish clay, a silicate of alumina, that is, into what remains of the rock after weathering has extracted the silicates of the alkalis and alkaline earths either by the carbonic acid in the form of carbonates or directly by the nitric acid.

Alkaline carbonates are not encountered among the salts of the pampa, as far as I know, so that if they have existed they must have been transformed into nitrates.

Perhaps the objection might be raised that the nitrate on the summit of the hills may not be in the same place in which it was formed, but has been carried there by the winds in the form of a fine powder. But this is not possible, for the prevailing winds are westerly and southwesterly and the Cerro de la Peineta (one of the hills that has a considerable quantity of nitrate on its summit) has no nitrate pampa on its west but is situated at the western edge of the nitrate region.

Applying the theory of Pissis to the interesting distribution of nitrate in Tarapacá, it results that the nitrate is encountered on the eastern edge of the coast range because it consists of the feldspathic porphyrites which have yielded the necessary sodium, whereas in the great plain which with a breadth of twenty to thirty kilometers rises with a slight gradient to the foot of the Andes this porphyritic material is not encountered.

It is also necessary to take into consideration that the nitrate in Tarapacá is not found only on the eastern edge of the coast range but also further west in various pampas within the range and at such elevations as seems impossible for the subterranean waters of the great pampa to the east to have reached. The subterranean waters that are actually encountered in these pampas owe their origin to the "camanchacas" or fogs which during the night are very wet. A fact showing that the moisture of the "camanchacas" penetrates to great depth is that during the war of 1879 to 1884 when most of the oficinas were shut down, there disappeared at one of them, as a result of the "camanchaca," thirty thousand quintals of refined nitrate stored on the cancha. A part of this nitrate was recovered by sinking wells to the groundwater, which was found to contain much nitrate, and by evaporating it.

LORENZO SUNDT.

SANTIAGO DE CHILE.

Sir:—The discussion by Mr. Sundt of our paper on the genesis of the Chilean nitrate deposits has interested us very much. Mr. Sundt has had such a long and varied experience on the nitrate pampas that a statement of his views on this subject is gladly received and is a decided contribution to the subject.

Mr. Sundt's theory, which is as he says similar to that of Pissis, to account for the formation of sodium nitrate is a plausible one and probably much sodium nitrate has been formed in that way. It seems to us almost impossible, however, to account for the present large deposits of nitrate as accumulations "in situ" of sodium nitrate so formed. The two conditions postulated as essential to its generation—the small amount of nitric acid in the air and the presence of feldspathic rocks to yield the soda—are met over an area far more extensive than is the occurrence of the nitrate deposits. As the physical and chemical processes at work effecting rock decay are the same throughout the desert region of Chile, nitrate deposits should have been formed wherever feldspathic rocks occur. Since they have not, it is obvious that the union of atmospheric nitric acid with the soda resulting from the decomposition of feldspars will not suffice to explain the nitrate deposits. Even if granted that the nitrate was formed in this way, there still remains the no less important problem of the accumulation of the enormous masses of it in more or less local areas.

As we emphasized in our paper, it is our opinion that no explanation which confines itself to the *mode of formation* of the sodium nitrate can be a satisfactory or complete one. We purposely confined ourselves in that paper to a consideration of the *manner of the localization* of the deposits, irrespective of how the nitrate was originally formed. There are a number of ways in which nitrates can be formed in nature and any one or all of these may have contributed to the nitrates of the Chilean deposits. But the *deposits* exist only as the result of the local accumulations of the nitrates. How did these accumulations take place? This question has been but little touched upon by writers in the past and is likewise overlooked by Mr. Sundt.

It is true that there are many phenomena of occurrence that are difficult to explain on the basis of our theory of accumulation, but the theory is a satisfactory explanation of the general facts of occurrence of the deposits and particularly, as he himself says, of their occurrence in the most important district, that of Tarapacá. No one has yet demonstrated any conditions favorable to the formation of nitrates by the presence of which this region is peculiarly favored. But the region is unique, on the one hand, in the presence of the nitrate deposits; and it is unique, on the other hand, in the combined conditions of climate, underground waters, and geologic structure. Moreover these conditions are competent to cause the local accumulations of widely disseminated nitrates. It is reasonable, therefore, to regard the existence of these conditions as the cause of the formation not of the nitrates but of the nitrate deposits.

JOSEPH T. SINGEWALD, JR.,
BENJAMIN LEROY MILLER.

Sir:—Returning to the question of the origin of the Chilean nitrates, I see that Messrs. Singewald and Miller have not attached the merited importance to the fact mentioned by me that the topography of many important nitrate deposits and the complete absence in them of groundwater make absolutely impossible the accumulation of the nitrate from groundwater, for that does not exist and never has existed in those deposits. The nitrate of such places was necessarily formed where it now is or on the slopes of the neighboring hills. It is recognized that the nitrate formed on the steeper slopes has passed down to the gentler slopes at the foot of the hills, for, although there may be nitrate on the top and at the base of a hill, very rarely is nitrate encountered where the slopes are highly inclined. This is as would be expected in view of the great solubility of the nitrate and the facility with which it absorbs the nocturnal moisture, without taking into account the occasional rains. In this way the deposit at the foot of the hill may have been enriched somewhat, but with nitrate which could have had no other than atmospheric origin.

I will add further that there are extensive nitrate terranes in which wells eighty meters deep have not encountered groundwater.

Messrs. Singewald and Miller ask: Why are not nitrate deposits found throughout the Atacama desert, where the same climatic and geologic conditions prevail? This is another question entirely, which can have many reasons and which the theory of Pissis is not obliged to answer. Nevertheless, I shall attempt to indicate several of the causes which may have been of influence.

It is true that in the Atacama desert there are great areas without nitrate deposits. Also in the same nitrate pampa there are stretches rich in nitrate bounded by terranes completely barren. There may be encountered a patch of caliche several meters in thickness and others only two or three meters in diameter. To explain these differences is not only very difficult but often impossible. However, it is necessary to distinguish between the origin of the nitrate deposits and their conservation. In regard to the origin, it should be determined if the favorable rocks actually exist, that is, porphyrites and basic lavas, for the acidic rocks do not appear to be favorable.

The conservation of a substance so easily soluble as nitrate depends on: (1) The rains, the force of which can vary from point to point and the superficial and subterranean streams derived from which may dissolve more nitrate in one place than in another. (2) The winds, the erosive force of which, as is known, is very great in the deserts and varies with the topography. (3) The inclination of the surface. We have seen that the nitrate is not preserved on a steep slope. Nor does the nitrate accumulate in large quantities in a terrane completely horizontal (as for example, in the "salares" and "salinas") due either to a capillary migration to higher and drier ground or because it is destroyed by anaërobic microbes. (4) Who knows how many unknown factors?

Now I ask: Is the groundwater theory capable of explaining

satisfactorily the accumulation of the nitrate in one place and its absence in another?

LORENZO SUNDT.

SANTIAGO DE CHILE.

Sir:—The foregoing letter of Mr. Sundt in discussion of the genesis of the Chilean nitrate deposits does not require additional comment on our part, unless a few words are added in reference to two points made by him.

We have previously shown that the theory advanced by Pissis and Sundt fails of being a satisfactory theory because it does not explain how the nitrates have accumulated into the existing deposits. To meet this objection, Mr. Sundt is inclined to look upon them as conserved remnants, and to a limited extent local accumulations of originally more widely distributed nitrates. But, the factors that he mentions as determining this conservation—irregular distribution of rainfall, erosive action of the wind, and inclination of terrane—fail to explain either the distribution or amount of the deposits. Irregular rainfall and eolian erosion could not possibly bring about or rather result in such distribution as we described in the Tarapacá field, or in fact as he describes in the Taltal district. Further, in spite of its deliquescent nature, without the aid of groundwater, the nitrate could not have made the migrations called for to explain the distribution and amount of accumulation. A surficial "crawling" up inclined slopes by capillary action to higher and drier terranes may explain local accumulations or enrichments, but completely fails to account for accumulations such as exist in the Tarapacá field.

The second point referred to is his insistence that the topographic position of many of the deposits is such that they could not be reached by groundwater. To this we reiterate that the largest and most important deposits *are* related to groundwater in the manner called for and upon which our theory is based. If it can be demonstrated that in some cases no such relation exists, the natural and logical assumption (in view of the general

agreement) is that the relation has been destroyed since the deposits were formed. There is abundant evidence of extensive diastrophic changes in the Andes during recent geologic time, and it is not unreasonable to expect that they may have brought about local changes in groundwater level.

In conclusion we wish to call attention to a paper on the subject by Mr. Sundt which contains a fuller presentation of his views and which should have been included in the selected bibliography published in connection with our original paper. It was published in the Trabajos del Cuarto Congreso Cientifico (1° Pan Americano), III. Sección, Tomo i, 1911, pp. 512–520, Santiago de Chile, under the title "El Origen del Salitre Chileno y de Algunas Sales que lo Acompañan."

JOSEPH T. SINGEWALD, JR.,
BENJAMIN LEROY MILLER.

Sir:—In the review of "Microscopical Determination of the Opaque Minerals" by Joseph Murdoch, Dr. Bastin has not considered the addition of a new term to the nomenclature of geology. Dr. Murdoch after a rather full discussion has proposed the word "mineralography" to cover the study of minerals by reflected light. While it might be inferred from Dr. Bastin's failure to mention the matter that he has tacitly accepted the term, it is believed that obscurity of nomenclature may be somewhat alleviated by early discussion of additions to terminology and in the present communication it is the purpose to present "mineralography" to the consideration of economic geologists.

"Mineralography," a parallel to "mineralogy," is derived from the late Latin *minerale,* a mineral or ore, and the Latin *graphia,* writing. According to the accepted use of such terms as "petrography" and "metallography," it may be properly applied to the microscopic study of minerals, while its similarity to "metallography" would suggest that this study is by means of reflected light. Objections to "mineralography" on the basis of the wide scope of the term, inclusive not only of opaque but transparent minerals, would seem invalid. Ruby silver, cerar-

gyrite, iodides and bromides of silver, zincblende, hematite and limonite are transparent constituents encountered in polished sections of ores. Gangue relations and microstructures, as twinning of calcite, are often easily detected in reflected light and polished sections have been used by McDowell[1] in the examination of the transparent minerals of silica brick. From these considerations it seems that a term like "opacography," derived from the Latin *opacus,* dark or opaque, and *graphia,* would have too narrow significance and that the wider applicability of "mineralography" would determine the choice of the latter.

The writer, therefore, is inclined to endorse Dr. Murdoch's selection in its derivation; but upon the ground of euphony feels compelled to modify it. A more euphonious term, one more nearly parallel to "mineralogy" and yet one connoting better the connection of the study with ores rather than with minerals, is suggested—namely "mineragraphy."

W. L. WHITEHEAD.

[1] McDowell, J. S., "A Study of the Silica Refractories," *Am. Inst. Min. Eng. Bull.,* 119, Nov., 1916, pp. 2051–2052.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

METALLIFEROUS.

GOLD.

Bull. 626. The Atlantic Gold District and the North Laramie Mountains, Fremont, Converse, and Albany Counties, Wyo. By A. C. SPENCER, U. S. G. S., 1916.

Bull. 640–F. The Golden Arrow, Clifford and Ellendale Districts, Nye County, Nev. By H. G. FERGUSON, U. S. G. S., 1916.

Bull. 640–I. The Gold Log Mine, Talladega County, Ala. By E. S. BASTIN, U. S. G. S., 1916.

Bull. 642–F. Gold Mining in the Willow Creek District, Alaska. By S. R. CAPPS, U. S. G. S., 1916.

COPPER.

The Composition of Natural Bornite. By E. T. ALLEN, of the Geophysical Laboratory. Am. Jr. Sci., Vol. 41, No. 5, pp. 409–413, 1916.

He reviews previous work and shows that the formula is Cu_5FeS_4.

Observations on Certain Types of Chalcocite and their Characteristic Etch Patterns. By C. F. TOLMAN, JR. Bull. A. I. M. E., 1916, pp. 401–433.

The genesis of chalcocite is discussed and illustrated by photomicrographs.

LEAD AND ZINC.

Lead and Zinc Deposits in Ontario and Eastern Canada. By W. L. UGLOW. Vol. XXV., Pt. II., Ont. Bur. of Mines, Toronto, 1916.

IRON AND COBALT.

Magnetic Properties of Cobalt and of Fe_2CO. Pt. V. By HERBERT T. KALMUS and K. B. BLAKE. No. 413, Canada Dept. of Mines, Ottawa, 1916.

Researches on cobalt and cobalt alloys conducted at Queens University, Kingston, Ont., for the Mines Branch of the Dept. of Mines.

Bull. 100. Manufacture and Uses of Alloy Steels. By HENRY D. HIBBARD. Dept. of the Int. Bur. of Mines, 1916.

TIN.

The Origin of Topaz and Cassiterite at Gunary Bakau, Malaya. By WILLIAM R. JONES. Geol. Mag., Vol. 3, No. 6, pp. 255–260, 1916.

The evidence goes to show that the fluorine vapors converting the granite into greisen also produced the topaz and cassiterite.

Bull. 640–G. Tin Ore in Northern Londer County, Nev. By ADOLPH KNOPF. U. S. G. S., 1916.

ALUMINUM.

Die Klimatischen Bildungsbedingungen des Laterits. Von RICHARD LANG. Chemie der Erde, pp. 134–154, 1915.

MOLYBDENUM AND NICKEL.

Bull. 640–D. Molybdenite and Nickel Ore in San Diego County, Calif. By F. C. CALKINS. U. S. G. S., 1916.

ANTIMONY.

Bull. 649. Antimony Deposits of Alaska. By A. H. BROOKS. U. S. G. S., 1916.

RARE EARTH METALS.

On the Separation of Caesium and Rubidium by the Fractional Crystallization of the Aluminum and Iron Alums and its Application to the Extraction of these Elements from their Mineral Sources. By P. E. BROWING and S. R. SPENCER. Am. Jr. Sci., Vol. XLII., No. 249, 1916.

REGIONAL.

New Zinc Phosphates from Salmo, B. C. By A. H. PHILLIPS. Am. Jr. Sci., Vol. XLII., No. 249, 1916.

Bull. 640–E. Lode Mining in the Quartzburg and Grimes Pass Porphyry Belt, Boise Basin, Idaho. By E. L. JONES, JR. U. S. G. S., 1916.

Bull. 640–B. Reconnaissance in the Conconully and Ruby Mining Districts, Wash. By E. L. JONES, JR. U. S. G. S., 1916.

Bull. 642–B. Mining Developments and Water Power. Investigations in Southeastern Alaska. By THEODORE CHAPIN and G. H. CANFIELD. U. S. G. S., 1916.

Bull. 642–C. Mineral Resources of the Upper Chitina Valley, Alaska. By F. H. MOFFAT. U. S. G. S., 1916.

Bull. 642–D. Mining on Prince William Sound, Alaska. By B. L. JOHNSON. U. S. G. S., 1916.

Bull. 642–E. The Turnagain-Knik Region, Alaska. By S. R. CAPPS. U. S. G. S., 1916.

Bull. 642–G. Preliminary Report on the Tolovana District, Alaska. By A. H. BROOKS. U. S. G. S., 1916.

Bull. 642–H. The Cosna-Nowitna and Ruby-Kuskokwim Regions, Alaska. By H. M. EAKIN, J. B. MERTIE, JR., and G. L. HARRINGTON. U. S. G. S., 1916.

Bull. 648. Notes on Some Mining Districts in Eastern Nevada. By J. M. HILL. U. S. G. S., 1916.

NON-METALLIFEROUS.

OIL.

Bull. 134. The Use of Mud-Laden Fluid in Oil and Gas Wells. By J. O. LEWIS and W. F. MCMURRAY. Dept. of Int. Bur. of Mines, 1916.

The Origin of Petroleum and Asphalt. By CLIFFORD RICHARDSON, JR. Ind. Eng. Chem., Vol. 8, No. 1, 1916.

Bull. 641–C. Possibilities of Oil and Gas in North-Central Montana. By EUGENE STEBINGER. U. S. G. S., 1916.

Bull. 641–B. The Oil and Gas Geology of the Foraker Quadrangle, Osage County, Okla. By K. C. HEALD. U. S. G. S., 1916.

COAL.

Bull. 627. The Lignite Field of Northwestern South Dakota. By D. E. WINCHESTER, C. J. HARES, E. R. LLOYD, and E. M. PARKS. U. S. G. S., 1916.

Bull. 641–H. Geology of the Hound Creek District of the Great Falls Coal Field, Cascade County, Mont. By V. H. BARNETT. U. S. G. S., 1916.

PHOSPHATE.

Investigation of a Reported Discovery of Phosphate in Alberta. By HUGH S. DE SCHMID. Can. Dept. of Mines, Ottawa, No. 385, 1916.

The deposit is not of much economic importance. The phosphate body is small, has a low phosphoric acid content and a great deal of free silica.

FELDSPAR.

The Feldspars of the New England and North Appalachian States. By A. S. WATTS. Bull. 92, Mineral Technology 9, Dept. of Int. Bur. of Mines, 1916.

MARBLE.

The Technology of Marble Quarrying. By OLIVER BOWLES. Bull. 106, Mineral Technology 13, Dept. of Int. Bur. of Mines, 1916.

PRECIOUS STONES.

The Emerald Deposits of Muzo, Colombia. By JOSEPH E. POGUE, of Northwestern University. Bull. A. I. M. E., No. 5, 1916.

THEORETICAL.

The Growth of Crystals under External Pressure. By STEPHEN TABER. Am. Jr. Sci., Vol. 41, No. 6, pp. 532–556, 1916.

The forces developed during crystal growth may have been important in the formation of many mineral veins.

Studies in Hydrothermal Alteration. I. The Action of Certain Alkaline Solutions on Feldspars and Hornblende. By E. A. STEPHENSON, University of Chicago. Jr. Geol., Vol. 24, No. 2, pp. 180–199, 1916.

Feldspars were attacked by heated alkaline waters with the separation of silica and zeolites. Kaolin was not produced from alkaline solutions. It is inferred that kaolin is formed under the action of acid waters on minerals.

Über das Tonmineral, Montmorillonit und das Tonerdephosphat, Planerit. By HAMS LEITMEIER, of Doelter's Mineralogie Inst., University of Vienna. Z. Kryst. Min., Vol. 55, No. 4, pp. 353–371, 1916.

An amorphous and colloidal clay on standing in the laboratory became crystalline. It is believed to be a definite chemical compound of formula $Al_2Si_4O_{11}$. A white to blue aluminum phosphate is described in detail and is regarded as a colloid form of Planerit. The blue color in some specimens is due to a copper compound held by asorption.

The Occurrence of Ore on the Limestone Side of Garnet Zones. By JOSEPH UMPLEBY. University of Calif. Press, Vol. 10, No. 3, pp. 25–37, 1916.

The author brings forth evidence from seven contact metamorphic zones showing that ore occurs farther from the ore-bringing igneous rock than the lime silicates. This may be due to: (1) Lower temperature of formation of sulphides than of lime silicates and therefore they are at the outer edge of the margin of metamorphism. (2) The solutions changed compositions. The lime silicates are first formed. Later sulphide rich solutions replace limestone in preference to metamorphic minerals earlier developed. The author favors the second theory.

STATISTICAL.

Preliminary Report on the Mineral Production of Canada during the Calendar Year 1915. Prepared by JOHN MCLEISH. Can. Dept. of Mines, Ottawa, No. 408, 1916.

A Review of the Mining Operations in the State of South Australia during the Half Year ending December 31, 1915. No. 23. Compiled by LIONEL E. C. GEE.

Mineral Resources of the United States, 1914. Part I, Metals. H. D. McCaskey, geologist in charge, 1916. Part II, Nonmetals, 1916.
Statistics of the production, importation and exportation of metalliferous and nonmetalliferous mineral substances in the United States in 1914, etc.

Part of Mineral Resources of the United States, 1915, namely: Chromic Iron Ore in 1915. By J. S. Diller. 1916.

Bull. 642–A. The Alaskan Mining Industry in 1915. By A. H. Brooks. 1916.

Part of Mineral Resources of the United States, 1915, as follows:

Pottery in 1915. By Jefferson Middleton, 1916.
Secondary Metals in 1915. By J. P. Dunlop. 1916.
Manganese and Manganiferous Ores in 1915. By D. F. Hewitt. 1916.
Silver, Copper, Lead and Zinc in the Central States in 1915 (Mines Report). By J. P. Dunlop and B. S. Butler. 1916.
Talc and Soapstone in 1915. By J. S. Diller. 1916.
Potash Salts, 1915. By W. C. Phalen. With **Simple Tests for Potash.** By W. B. Hicks. 1916.
Asphalt, Related Bitumens, and Bituminous Rock in 1915. By J. D. Northrop. 1916.
Gypsum in 1915. By R. W. Stone. 1916.
Platinum and Allied Metals in 1915. By J. M. Hill. 1916.
Bauxite and Aluminum in 1915. By W. C. Phalen. 1916.
Gold, Silver, and Copper in Alaska in 1915. By A. H. Brooks. 1916.
Cement in 1915. By E. C. Burchard. 1916.
Sand and Gravel in 1915. By R. W. Stone. 1916.
Lime in 1915. By G. F. Loughlin. 1916.
Salt, Bromine, and Calcium Chloride in 1915. By W. C. Phalen.
Lead in 1915 (General Report). By C. E. Siebenthal. 1916.
Mica in 1915. By W. T. Shaller. 1916.
Sulphur, Pyrite, and Sulphuric Acid in 1915. By W. C. Phalen. 1916.
Gold, Silver, Copper, Lead and Zinc in California and Oregon in 1915 (Mines Report). By C. G. Yale. 1916.
Quicksilver in 1915. By H. D. McCaskey. 1916.
Iron Ore, Pig Iron, and Steel in 1915. By E. F. Burchard. 1916.
Barytes and Strontium in 1915. By J. M. Hill. 1916.
Phosphate Rock in 1915. By W. C. Phalen. 1916.
Mineral Waters in 1915. By R. B. Dole. 1916.

GEOCHEMISTRY.

Bull. 616. Data of Geochemistry (Third Edition). By F. W. Clarke. 1916.

TEXTBOOKS.

Microscopical Determination of the Opaque Minerals: An Aid to Study of Ores. By JOSEPH MURDOCH. New York, 1916, pp. vi, 163. (John Wiley & Son.)

Reviewed in ECONOMIC GEOLOGY, vol. XI., p. 691.

Economic Geology. By HEINRICH RIES. 4th Edition, 1916. (John Wiley & Son.)

BIBLIOGRAPHY.

The Mining World Index of Current Literature. Vol. VIII. Last half year, 1915. By GEO. E. SISLEY. Pp. xi, 228, xxv, Chicago, 1915 (Mining World Co.).

The book covers the world's current literature in this field. Reviewed in ECONOMIC GEOLOGY, Vol. XI., p. 598.

CONTRIBUTIONS TO ECONOMIC GEOLOGY.

Bull. 620–M. Preliminary Report on the Economic Geology of Gilpin Co., Colorado. E. S. BASTIN and J. M. HILL, 1916, pp. 295–323. Part of Bull. 620, "Contributions to Economic Geology," 1915, pt. I.

Bull. 621–L. Oil and Gas near Basin, Big Horn County, Wyo. C. T. LUPTON. 1916, pp. 157–190. Part of Bull. 621, "Contributions to Economic Geology," 1915, Pt. II.

Prof. Paper 98–A. Evaporation of Brines from Searles Lake, Calif. By W. B. HICKS. 1916, pp. 1–8. Part of Prof. Paper 98, "Shorter Contributions to General Geology," 1916.

Bull. 620–O. A Reconnaissance for Phosphate in the Salt River Range, Wyo. By G. R. MANSFIELD. 1916, pp. 331–349. Part of Bull. 620, "Contributions to Economic Geology," 1915, Pt. I.

Bull. 621–M. Geology and Oil Prospects of Cuyama Valley, Calif. By W. A. ENGLISH. 1916, pp. 191–215. Part of Bull. 621, "Contributions to Economic Geology," 1915, Pt. II.

Bull. 621. Contributions to Economic Geology (Short Papers and Preliminary Reports). 1915, Pt. II., Mineral Fuels, M. R. CAMPBELL and DAVID WHITE, geologists in charge. 375 pages, 25 plates, 17 text figures.

Comprises papers on petroleum in Calif., Mont., Ohio, Okla., Texas, and Wyo., natural gas in Texas and Wyo., and coal in Idaho and Mont.

SCIENTIFIC NOTES AND NEWS[1]

MR. CHESTER W. WASHBURNE has opened an office at 66 Liberty St., New York City, for the practice of geological work.

THE TWENTIETH ANNUAL three months mining session at the University of Washington has an attendance of forty-five men, all but ten of whom have had mining experience. They are drawn mostly from the Pacific Coast from Arizona to Alaska.

HORACE WINCHELL has gone to Russia for a few months.

FRED SEARLES is returning from a geological examination of Chinese properties.

WALDEMAR LINDGREN has gone to Chile in connection with geological work on some of the copper properties.

J. D. IRVING is giving a course of lectures on ore deposits at Columbia to supplement the work carried on in the absence of Professor Kemp.

FRANK D. ADAMS was elected president of the Geological Society of America at the annual meeting at Albany.

J. R. FINLEY has been at Globe and Jerome recently.

WILLIS T. LEE, of the U. S. Geological Survey, recently delivered two lectures before the Geological Club of Yale University on Mesozoic Physiography of the Southern Rockies.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.